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6 SPACECRAFT CHARGING

STANDARD REPORT.

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SUBMITTED TO:

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS,
SPACE DIVISION
LOS ANGELES AIR FORCE STATION
LOS ANGELES, CALIFORNIA

15 F04701-80-C-0008

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SPACECRAFT CHARGING

STANDARD REPORT

CDRL A005

INTERIM REPORT

30 SEPTEMBER 1980

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DEPARTMENT OF THE AIR FORCE
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FOREWORD

This report provides an interim version of a Spacecraft Charging Requirements Appendix to MIL-STD-1541. It has been generated by Science Applications, Inc. (SAI) as part of their Contract (F04701-80-C-0009) for SCATHA Data and Modeling Analysis. The report will be updated in FY81 and provided to AFSD and Aerospace Corporation for input to the MIL-STD-1541 revision.

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SECTION I
INTRODUCTION

1.0 STATUS OF SPACECRAFT CHARGING STANDARD DEVELOPMENT

The development of a military standard for spacecraft charging requirements is an essential product of the Cooperative NASA/AF Spacecraft Charging Investigation. Figure 1.0-1 presents a timeline of the history of this development over the past 4 years of the NASA/AF program. The current goal is the incorporation of S/C charging requirements into an update of MIL-STD-1541 by the end of Air Force FY82. Over the time period shown, the S/C Charging Standard has evolved from an initial identification of a need for an environmental and test specification, through a potential stand-alone military standard requirements document. to the now planned MIL-STD-1541 revision. The intent is to serve the community of system program offices, NASA labs, and space vehicle contractors with a document which provides a consensus of practical requirements for design, test, and analysis to minimize the effects of the S/C charging phenomena.

SAI has just completed a phase of reviewing the S/C Charging Standard inputs with the new AF and Aerospace Corporation SCATHA program management for the purpose of providing a fresh look into what can be incorporated within the milestones of the NASA/AF program. Section 2.0 of this introduction presents the high priority NASA/AF program activities which are essential for the military standard update. The planned schedule for the completion of these tasks is also shown. A structure for the contents has been defined and is detailed in Section 3.0. Section 4.0 presents the views of SAI on the practical utility of the S/C Charging Requirements and the supporting information generated in the joint NASA/AF program.

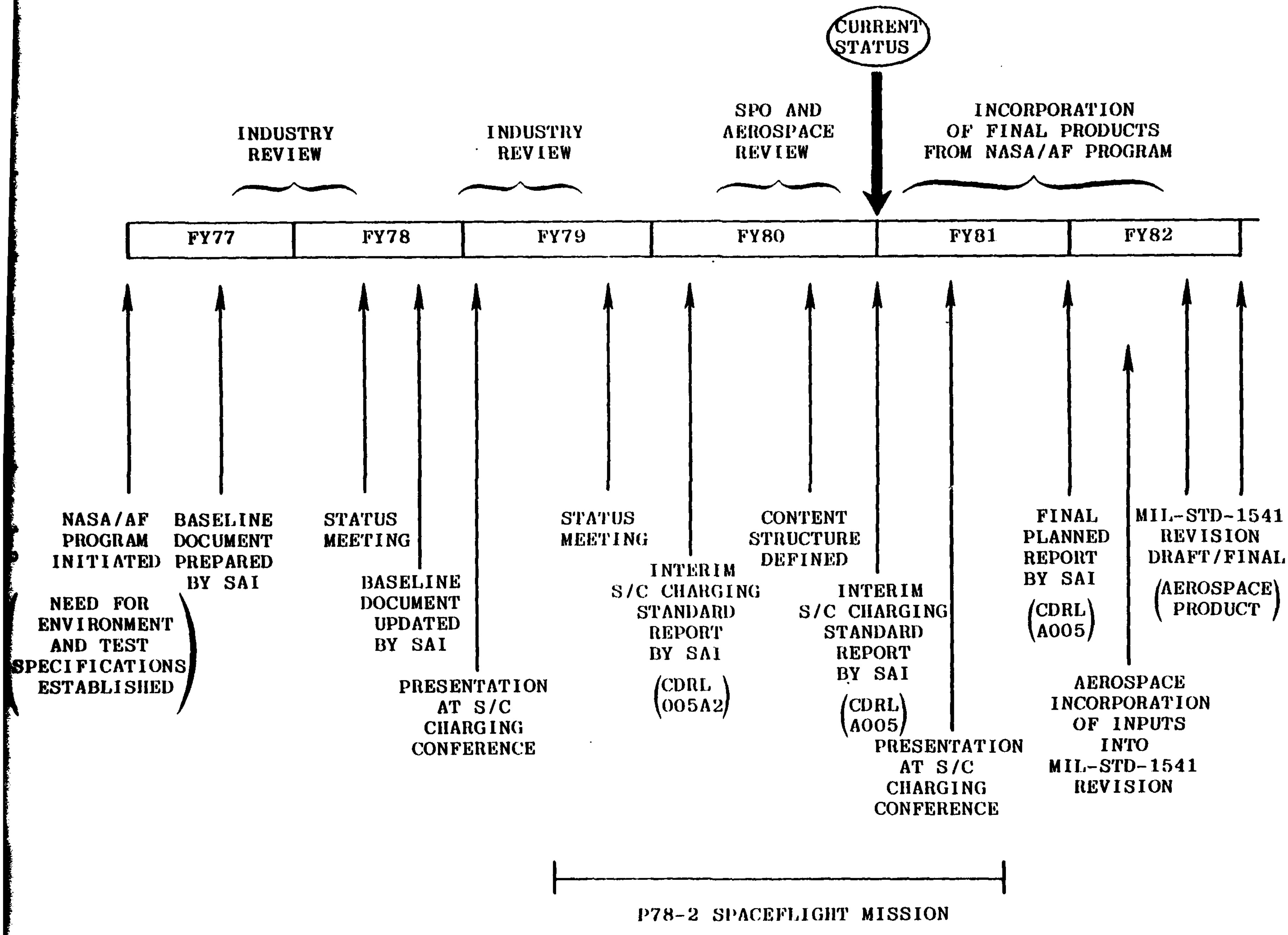


FIGURE 1.0-1 TIMELINE OF S/C CHARGING STANDARD DEVELOPMENT ACTIVITIES

The second major part of this report, Section II, provides the current contents of the MIL-STD-1541 revision in the format of a S/C Charging Requirements Appendix to be added to the MIL-STD-1541 document. An attempt has been made to quantify as much information as possible based on the current data available. Material with a high degree of uncertainty is flagged or left TBD at this time, with same "best available information" in parentheses.

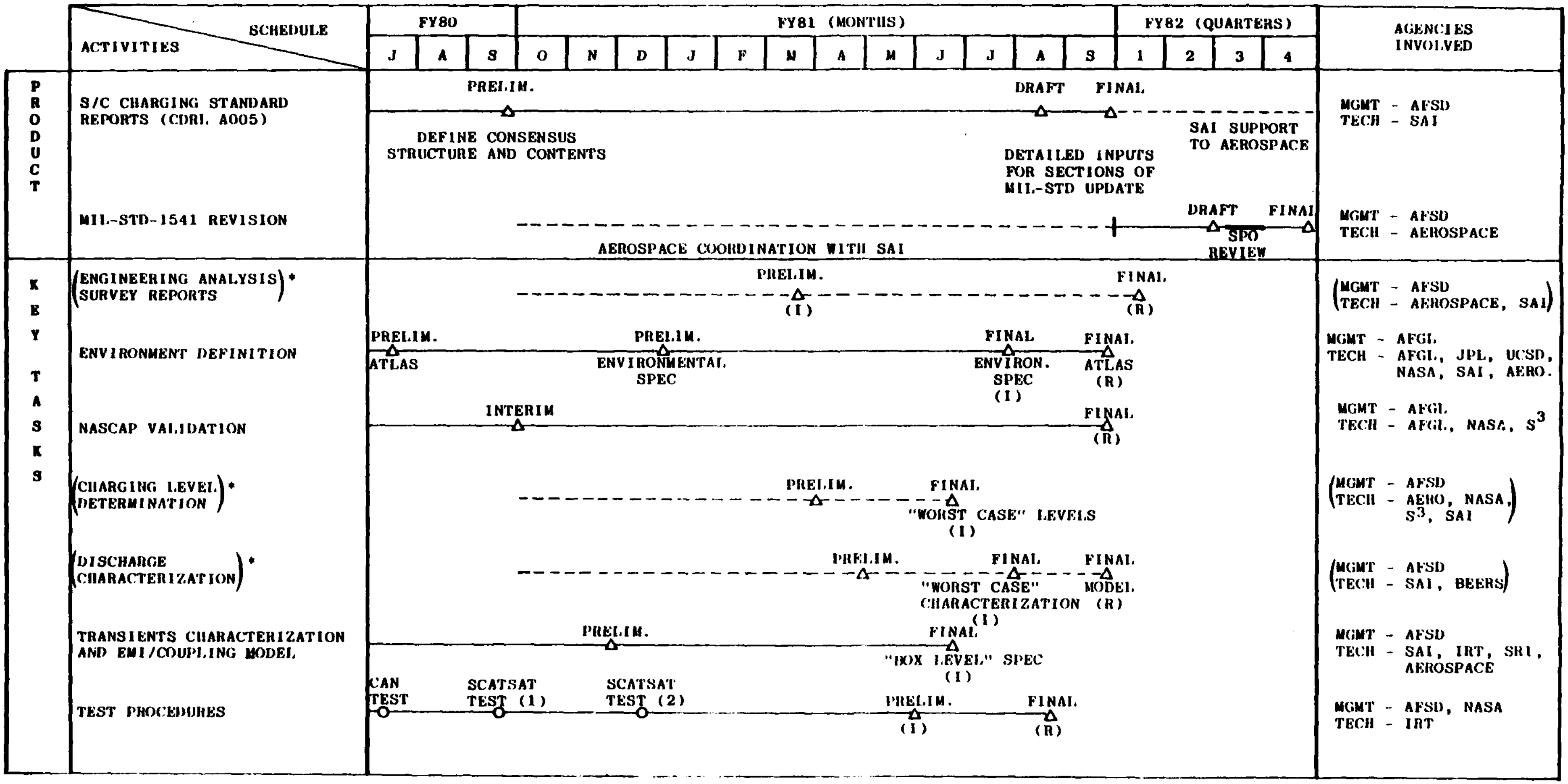
The third major part of this report, Section III, provides selected background information regarding the S/C charging requirements appendix. Major references and sources of information are provided. Further technical detail is presented, especially applicable to the justification of the inputs used in the MIL-STD-1541 update. The report concludes with a summary and recommendations for the concentration of efforts during the next two years to finalize the document revision.

2.0 KEY ACTIVITIES AND MILESTONES SCHEDULES

Certain activities are considered essential in providing the required inputs for a comprehensive military standard product. These are shown in Figure 2.0-1 along with the currently planned schedule and milestones for each task. Agencies involved, as members of the joint NASA/AF S/C Charging Investigation, are called out at the right of the figure. Tasks which are intended to be contracted by the Air Force for FY81 are shown in parentheses with their schedules dashed. Crucial milestones for direct inputs (I) to the SAI S/C Charging Standard Reports (CDRL A005) are indicated as well as final products to be referenced (R) only in the final MIL-STD-1541 revision. As a guideline, all essential inputs (I), should be received by SAI by 1 July, 1981.

The following comments are important to their representative tasks:

- The SAI Reports and the MIL-STD-1541 revision require a close and continuous coordination between



* TASKS TO BE CONTRACTED IN FY81 (I) = INPUTS TO STANDARD, (R) = REFERENCED IN STANDARD

SAI and the Aerospace Corporation to assure that SPO interests and community needs are comprehensively addressed.

- The Engineering Analysis Survey Report (to be issued by Aerospace Corp.) requires inputs from the SAI/SRI team on the TPM analysis.

- The environment definition (AFGL responsibility) requires a high intensity effort to be inclusive of a large and representative base of P78-2 data. A definition of the region of space pertinent to S/C charging effects is also required from AFGL.

- The sheath models are of lower priority than the other tasks for inclusion in the standard. The NASCAP validation is important for comparisons to P78-2 space data and to ascertain the utility of using simpler codes for charging analysis.

- The charging level determination task is required to establish "worst case" differential potentials on spacecraft of typical generic designs. To accomplish this, NASCAP (or another charging code), should be applied to sample S/C designs using a high intensity plasma environment (as determined from P78-2 data) as a source. An alternative is to base the "worst case" levels on P78-2 SSPM data alone, but this will not be representative of other S/C designs.

- The discharge characterization effort should be contracted for an early FY81 kickoff in order to meet overall program schedule requirements. A comprehensive discharge characterization program has been tasked to an SAI/Beers Associates team.

- The transients characterization requires intense effort by Aerospace Corp. (SC1-8B) and SAI/SRI (TPM) to complete a full survey and analysis of P78-2 data

- EMI/Coupling Analysis and the development of test procedures is of crucial importance to the MIL-STD-1541 revision. Collaboration is necessary among IRT, SAI, and Aerospace Corp. in this activity. IRT SCATSAT test program option II appears sufficient to build the basis for a recommended test approach for inclusion in the standard.

To assure the timely completion of interim products within this milestone schedule, the SPO must assume an active role in closely monitoring all key tasks and activities. Additionally, the allocation of funds within budget constraints should be directed with emphasis on high priority tasks. The overall management of this activity with the goal of a MIL-STD-1541 revision in FY82 is a substantial undertaking.

3.0 STRUCTURE OF MIL-STD-1541 REVISION

The military standard requirements for spacecraft charging will take the structure of an appendix to the MIL-STD-1541 document. Elements within the main body of the current MIL-STD-1541 relating uniquely to S/C charging will be deleted in the formal revision by Aerospace Corporation.

It is intended that the region of space of direct concern for S/C charging effects be defined by AFGL in the Environmental Atlas (with coordination by Aerospace Corp). Any space system under consideration that would enter this region during the course of its mission, would be subject to the requirements of the S/C Charging Appendix. Aerospace Corporation will clearly feature this as an applicability statement (inclusion or exclusion clause) in Section 1.0 SCOPE of MIL-STD-1541 in the revision. A recommendation for the text for this "inclusion" clause follows:

Text For Section 1.__ APPLICATIONS

Appendix TBD of this document, Spacecraft Charging Requirements, shall be applicable only to space systems which might enter, during the course of their mission, the region of space containing the plasma environment which can cause spacecraft charging effects. This region of space is defined in TBD (Final AFGL Atlas).

Note: A brief summary of the applicable region may also be included (e.g. regions between L shell values of 4.0 and 9.0).

Section II of this report provides the SAI recommended inputs for the Spacecraft Charging Requirements Appendix, following the format as specified by MIL-STD-962. The main sections of the appendix are:

10. SCOPE
20. REFERENCED DOCUMENTS
30. DEFINITIONS
40. GENERAL STATEMENT OF REQUIREMENTS
50. DETAILED STATEMENT OF REQUIREMENTS

Table 3.0-1 provides a brief description of the contents of each section.

4.0 UTILITY OF MIL-STD-1541 REVISION

To date, contractors have had no definitive requirements regarding S/C charging effects upon which they could properly plan and implement a program of design, analysis, and test for the susceptibility of their space systems to this phenomena. Requests for proposals (RFPs) for major space systems have included preliminary requirements which have little justification and are based on a limited data set of postulated events on-orbit or rudimentary ground tests. Program offices as well as contractors need a clearer, more precise, and comprehensive set of requirements for spacecraft charging effects.

TABLE 3.0-1 Spacecraft Charging Requirements Appendix (MIL-STD-1541 Revision) Structure

SECTION	CONTENTS
10. SCOPE	Addresses scope, purpose, and applicability of requirements for S/C charging protection.
20. REFERENCED DOCUMENTS	Lists applicable government (and other) documents which supplement information in MIL-STD-1541 with respect to S/C charging effects.
30. DEFINITIONS	Definitions and acronyms to clarify text updated to include S/C charging requirements.
40. GENERAL STATEMENT OF REQUIREMENTS	General system performance and design requirements inclusive of calling out the preparation of an analytical plan, a test plan, and the inclusion of "generalized" design guidelines.
50. DETAILED STATEMENT OF REQUIREMENTS	Specific system and subsystem requirements for S/C charging protection including: o detailed design requirements o test requirements and test methods o analysis approaches

It is the intent for Section II of this report to provide a foundation for this requirements document. In final appendix form, it shall be incorporated as the primary revision to MIL-STD-1541 for S/C charging.

The Spacecraft charging requirements are designed to assure program offices that all features regarding the susceptibilities of space systems to S/C charging are addressed. At the same time, the requirements are stated in an unambiguous manner to permit contractors to practically scope the efforts required for design, analysis, and test so that they may rationally bid on this activity within their space system program budget. It is recognized that contractors may seek waivers from selected spacecraft charging requirements (shielding requirements, test levels, etc.). This is clearly possible if the contractor can show, through analysis or test, that his particular design is less susceptible to the specified S/C charging environment than that of a generalized design assumed in defining the requirements. Additionally, certain program offices may wish to delete or change requirements they feel are not appropriate to their programs. This can be controlled within the Statement of Work (SOW) by carefully tailoring the requirement for the applicability of MIL-STD-1541 and the S/C Charging Requirements Appendix.

SECTION II
MIL-STD-1541 Revision
APPENDIX: SPACECRAFT CHARGING REQUIREMENTS

This appendix includes mandatory material to be considered as part of this standard as prescribed in paragraph TBD of this standard. (Paragraph TBD is the applicability statement within body of MIL-STD 1541).

10. SCOPE

10.1 Scope. This appendix establishes the spacecraft charging (SCC) protection requirements for space vehicles which are to operate in the magnetospheric plasma environment as specified in TBD (AFGL Final Environmental Atlas - definition of applicable region of space).

10.2 Application. This appendix shall be applicable only to space systems which might enter, during the course of their mission, the region of space containing the plasma environment which can cause spacecraft charging effects. This region is defined in TBD (Final AFGL Atlas). (Regions of space in the vicinity of the earth with L shell values of between 4.0 and 9.0 are representative of the regions of the SCC hazard). This appendix shall apply generally to all space systems exposed to the SCC hazard. Certain requirements may, however, be specifically tailored to individual program specifications with the approval of the procuring agency

20. REFERENCED DOCUMENTS

20.1 Issues of Documents. The following documents of the issue in effect on the date of invitation for bids or request for proposal, form a part of this Appendix to the extent specified herein:

STANDARDS

Military

MIL-STD-1541 (USAF) - Electromagnetic Compatibility Requirements for Space Systems

20 2 Other Publications. The following documents form a part of this appendix to the extent specified herein. Unless otherwise indicated, the issue in effect on the date of invitation for bids or request for proposal shall apply.

NASA TM X-73446 - Provisional Specification for Satellite Time in a Geomagnetic Substorm Environment (to be updated)

AFML-TR-76-233 - Conductive Coatings for Satellites

AFML-TR-77-174 - Transparent Antistatic Satellite Materials

AFML-TR-77-105 - Spacecraft Static Charge Control Materials

AFML-TR-78-15 - Satellite Contamination

AFGL-TR-77-0288 - Modeling of the Geosynchronous Orbit Plasma Environment - Part I

AFGL-TR-78-0304	- Modeling of the Geosynchronous Orbit Plasma Environment - Part II
AFGL-TR-79-0015	- Modeling of the Geosynchronous Orbit Plasma Environment - Part III
NASA (to be published)	- Design Guidelines for Spacecraft Charging Monograph
NASA CR-135259	- NASCAP User's Manual
AFGL (to be published)	- Final Environmental Atlas, Preliminary version: P78-2 SCATHA Preliminary Data Atlas
AFWAL-TR-80-4029	- Satellite Spacecraft Charging Control Materials

30. DEFINITIONS

30.1 Definitions That Apply To This Appendix. The terms used in this appendix are either defined in MIL-STD-1541 (USAF) or listed in the following paragraphs.

30.1.1 Arc Discharge (Vacuum Arc Discharge). A discharge taking place in a vacuum region with initially high potential gradients. The electric field may exist within a dielectric or in the vacuum region surrounding the charge retaining material. In the latter case, the gradients are between the electrode and either the vacuum chamber walls or an equivalent space charge surrounding the electrode. In these cases, the potential gradients must be sufficiently high to ionize and vaporize the charge retaining material. There are different types of important vacuum arc discharges, each classified by the configuration of the electrodes or the characteristics of the current path at the spark gap. These are the dielectric-to-metal discharge and the metal-to-metal discharge, each with a spark gap path that is classified as a punch-through, a flash-over, or a blow-off discharge.

30.1.2 Blow-off Discharge (Space Emission Discharge). A vacuum discharge characterized by the ejection of current (blow-off of charge) into space surrounding an electrode. To produce a space emission discharge, the electric field must be sufficiently high to cause ionization and vaporization at the electrode.

30.1.3 Backscattering. The deflection of particles by scattering processes in matter such that particles emerge through the same planar surface as they entered.

30.1.4 Capacitive Direct Injection (CDI). A method of inducing a space vehicle response that simulates that response to a blow-off discharge. The method involves driving the space vehicle with a current injection into a given point, with charge return accomplished through a drive plate serving as a capacitor.

30.1.5 Dielectric-To-Metal Discharge. A discharge between two electrodes, one of which is a dielectric charge retaining material and the other is a conductive (metal) electrode in the vicinity of the dielectric. A dielectric material will typically accumulate charge when irradiated by electrons or ions or under certain conditions when placed in a plasma environment.

30.1.6 Differential Charging. The charging of neighboring space vehicle surfaces to differing potentials by the combined effects of space plasma charging, photoemission, secondary emission, and backscatter.

30.1.7 Faraday Cage. An electromagnetically shielded enclosure. The term generally refers to a conductive metallic structure, package, or mesh which attenuates external electromagnetic energy to specified levels in the interior.

30.1.8 Flash-Over Discharge. A discharge characterized by a current path that travels along a surface of the material (and sometimes around an edge) to close the path between the electrodes.

30.1.9 Geomagnetic Substorm Activity. The conditions near geosynchronous altitude during the injection of substorm particles into the earth's magnetic field, including disturbances in the dipole field and increased plasma energies and current densities.

30.1.10 Magnetospheric Plasma. The space plasma environment constituent in the magnetosphere. This is an electrically neutral collection of electrons and positive ions (primarily protons) with densities near geosynchronous altitude on the order of one particle/cm^3.

30.1.11 Metal-To-Metal Discharge. A discharge between two conducting electrodes.

3.1.12 Photoemission. An effect whereby radiation of sufficiently short wavelength impinging on substances causes electrons to be emitted with an energy that varies with the frequency of the radiation.

3.1.13 Punch-Through Discharge. A discharge through the bulk of a dielectric material coupled with a bulk breakdown of the insulating strength of the dielectric separating two electrodes. The current path is through the bulk of the material, with surfaces on opposite sides of the dielectric acting as electrodes. The punch-through discharge may occur in vacuum or in air.

3.1.14 Replacement Current. Current that flows to the electrodes in response to a discharge but not as part of the discharge.

3.1.15 Secondary Emission. An effect whereby low energy electrons or ions, called secondary electrons or ions, are emitted from a material as a result of the interaction of higher energy electrons or ions with the material. The ratio of secondary particles to primary particles can be greater than unity.

30.1.16 Spacecraft Charging (SCC). The phenomenon where space vehicle elements and surfaces can become differentially charged to a level sufficient to cause discharges and resulting EMI. The primary effects of SCC are electrical transients and upsets, material degradation and enhanced contamination.

30.2 Acronyms Used in This Appendix.

CDI - Capacitive Direct Injection
EMI - Electromagnetic Interference
ESD - Electrostatic Discharge
MLI - Multi-Layer Insulation
S/C - Spacecraft
SCC - Spacecraft Charging

40. GENERAL STATEMENT OF REQUIREMENTS

40.1 Spacecraft Charging Protection Program. The contractor's spacecraft charging protection program shall include (a) the preparation and maintenance of an analytical plan and (b) the preparation and maintenance of a test plan. The intent of the program shall be to assure that the space vehicle is capable of operating in the specified space plasma charging environment (Section 40.1.1) without degradation of the specified space vehicle capability and reliability and without changes in operational modes, location, or orientation. This performance must be accomplished without the benefit of external control such as commands from a ground station. The spacecraft charging protection program, the analytical plan, and the test plan shall be subject to approval by the procuring agency.

40.1.1 Specified Environment. The space plasma charging environment shall be that as specified in TBD (AFGL Final Environmental Atlas). Other AFGL documents useful to model the plasma environment include: AFGL-TR-77-0288, AFGL-TR-78-0304, and AFGL-TR-79-0015. A "worst case" engineering specification for that environment follows.

A "worst case" substorm is described as a plasma environment composed of electrons (e) and protons (p) with the following temperature and density for the given time intervals (see Figure 40.1-1).

40 1.2 Performance. Analysis and test shall be used to assure that all space vehicle electrical systems perform to specified capabilities in the specified environment. Specified capabilities and levels of performance shall be established by the procuring agency.

40.1.3 Design. Protective design measures shall be compatible with MIL-STD-1541 (USAF) and TBD (NASA Design Guidelines) to limit the susceptibility of electrical systems and spacecraft materials to the SCC hazard. Materials used in the space vehicle design shall perform to specified capabilities in the specified environment. The space vehicle design shall limit contamination enhanced by electrostatic effects induced by the specified environment to contamination levels that will not reduce the performance of space vehicle surfaces or systems below specified capabilities. Any protective features incorporated in the space vehicle design to reduce the SCC hazard must not reduce space vehicle performance below specified levels.

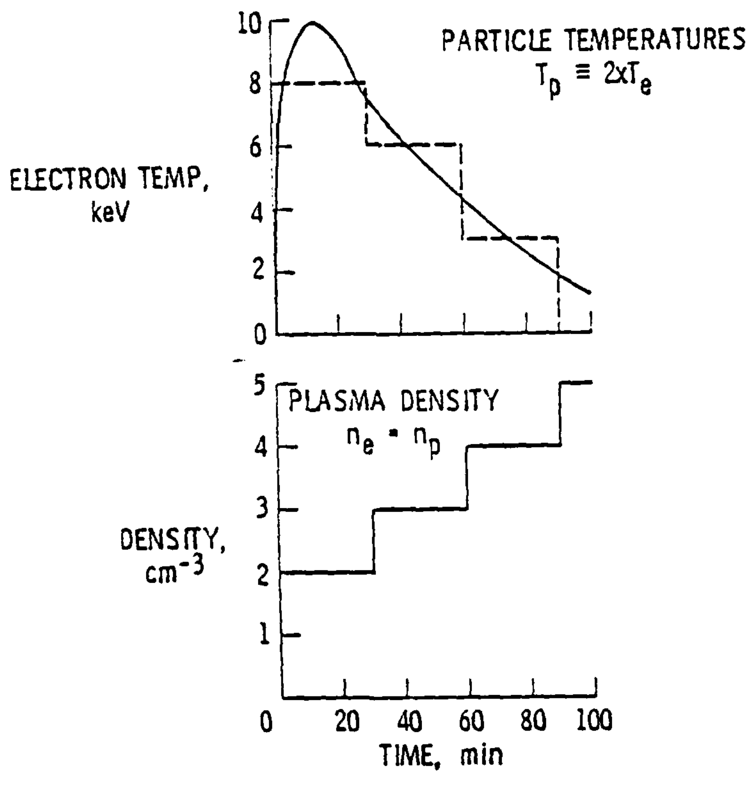


Figure 40.1-1 "Worst Case" Substorm Parameters

50. DETAILED STATEMENT OF REQUIREMENTS

50.1 Performance.

50.1.1 Electrical Subsystems and Systems. Space vehicle electrical subsystem and system outage shall be permissible during an arc discharge if operation and performance returns to specified levels within a telemetry main frame period after onset of the discharge or within some other period as defined by the procuring agency. A command to the space vehicle from an external source such as a ground station is not required to be completed if an arc discharge occurs during transmission of the command, provided that an unintended action does not result and that the space vehicle is capable of receiving and executing subsequent commands and meeting specified performance. Space plasma-induced electrical transients shall not affect on-board digital data beyond the specified design limits.

50.1.2 Materials. Thermal control materials and their surfaces, second surface mirrors, solar cells and coverslides, and other critical materials, structures, and components shall not degrade in thermal or optical properties or structural integrity in the specified space plasma environment below the level required to perform to specified capabilities.

50.2 Design.

The following design requirements (50.2.1 through 50.2.5) shall be implemented for protection against the SCC hazard. Additionally the design guidelines in TBD (NASA Design Guidelines Monograph) should be followed wherever reasonable and applicable. Where it is impractical or undesirable to implement the following design requirements, the contractor shall show by analysis or test that non-concurrence with the requirement will not degrade space vehicle performance below specified capabilities.

50.2.1 Grounding of conducting elements. All space vehicle conducting elements shall be tied by an electrical grounding system so that the DC resistance between any two points is $\leq$ 0.1 ohm. The grounding shall be applicable to all conducting elements with external surfaces exposed directly to the specified plasma environment and for all elements with surface areas $\geq$ 25 cm^2. DC resistance levels of grounds shall be verified by standard ohm-meter measurements. The grounding does not apply directly to thin ($<$ 10μ) conducting surfaces on dielectric materials. These are treated separately in Section 50.2.2.

50.2.2 Grounding of thin conducting surfaces. All thin ($<$ 10μ) conducting surfaces on dielectric materials shall be electrically grounded to the common space vehicle structural ground so that the DC resistance between the surface and the structure is $\leq$ 10 ohms. DC resistance levels of grounds and bonds shall be verified by standard ohm-meter and bond-meter measurements. Thicker surfaces shall be grounded as described in Section 50.2.1. Thin conducting surfaces shall be inclusive of, but not limited to, all metallized surfaces of multi-layer insulation (MLI) thermal blankets, metalized dielectric materials in the form of sheets, strips, tapes, or tiles, conductive coatings, conductive paints, conductive adhesives, and metallic grids or meshes. The number of ground points on each conducting surface should follow the following prescription:

Surface Area	Number of Ground Points
$<$ 1.0 m^2	2 or more
1 0 to 4.0 m^2	3 or more
$>$ 4.0 m^2	1 per m^2

Additionally, any point on a conducting surface should be within 1 meter of a grounding point.

50.2.3 Shielding of EMI. All electronic cables circuits, and components shall be provided with EMI shielding to attenuate radiated fields from discharges (100 kHz to 1 GHz) by at least 40 db. Attenuation levels of radiated fields shall be verified by standard measurement techniques or by analysis for representative locations internal to shielding enclosures. The method of verification shall be subject to approval by the procuring agency. The shielding may be provided by the basic space vehicle structure designed as a "Faraday cage" with a minimum of openings or penetrations, by enclosures of electronics boxes, by separate cable shielding, or by combinations of the preceding shields. Electronics units and cables external to the basic space vehicle structure shall have individual shields providing the 40 db attenuation of EMI.

50.2.4 Filtering of electrical transients. Sensitive electronic circuits shall be designed with filters to provide protection against high frequency (up to 100 MHz), large amplitude (TBD amperes), fast rise time (< 10 nanoseconds) pulses of up to 10 μseconds duration. Sensitivity of individual circuits and components shall be determined through test or analysis. Subsystem and system level pulse injection tests (see Section 50.4) shall be used to verify the effectiveness of the filters employed. Pulses shall be representative of those generated by the coupling of EMI from SCC associated discharges to the spacecraft wiring harnesses. Characteristics of SCC associated discharges are described in Section 50.2.4.1.

50.2.4.1 SCC associated discharge characteristics.

TBD. The preliminary format for the characterization of typical "worst case" SCC associated discharges follows:

The "worst case" characterization of a SCC associated discharge includes the following parameters:

1. Blow-off and arc current time history (probably monopolar, with rise time of 5 to 100 nanoseconds, dependent on sample linear dimensions; decay times to several μseconds, dependent on RC time constant of the sample; total charge in blow-off or integral of blow-off current is probably proportional to sample area; see Figure 50.2-1).

2. Electric and magnetic fields (described as functions of distance and time; dependent on motion of blow-off charge; configuration dependent).

3. Total energy content (stored, radiated, and dissipated energies; probably in range of 1 mjoule to 1 joule).

4. Breakdown conditions (extrapolations of ground test data to space conditions)

Additionally, scaling relationships and functional dependencies for the above parameters will be included here or referenced in a supporting document. The discharge characterization is dependent on type of material, sample area, thickness, configuration, charging current density and energy distribution, and irradiation history. Discharges will be described for materials which are commonly used on spacecraft and known to exhibit charging/discharging effects. Parameters listed above and in the following figure will be quantified as information becomes available.

50.2.5 Materials selection. Materials used in the space vehicle design shall be selected to minimize differential charging (see Section 50.2.5.1) and discharging (see Section 50.2.4.1) effects from the specified environment while maintaining specified performance capabilities. All materials used on exposed surfaces should be tested or analyzed to determine

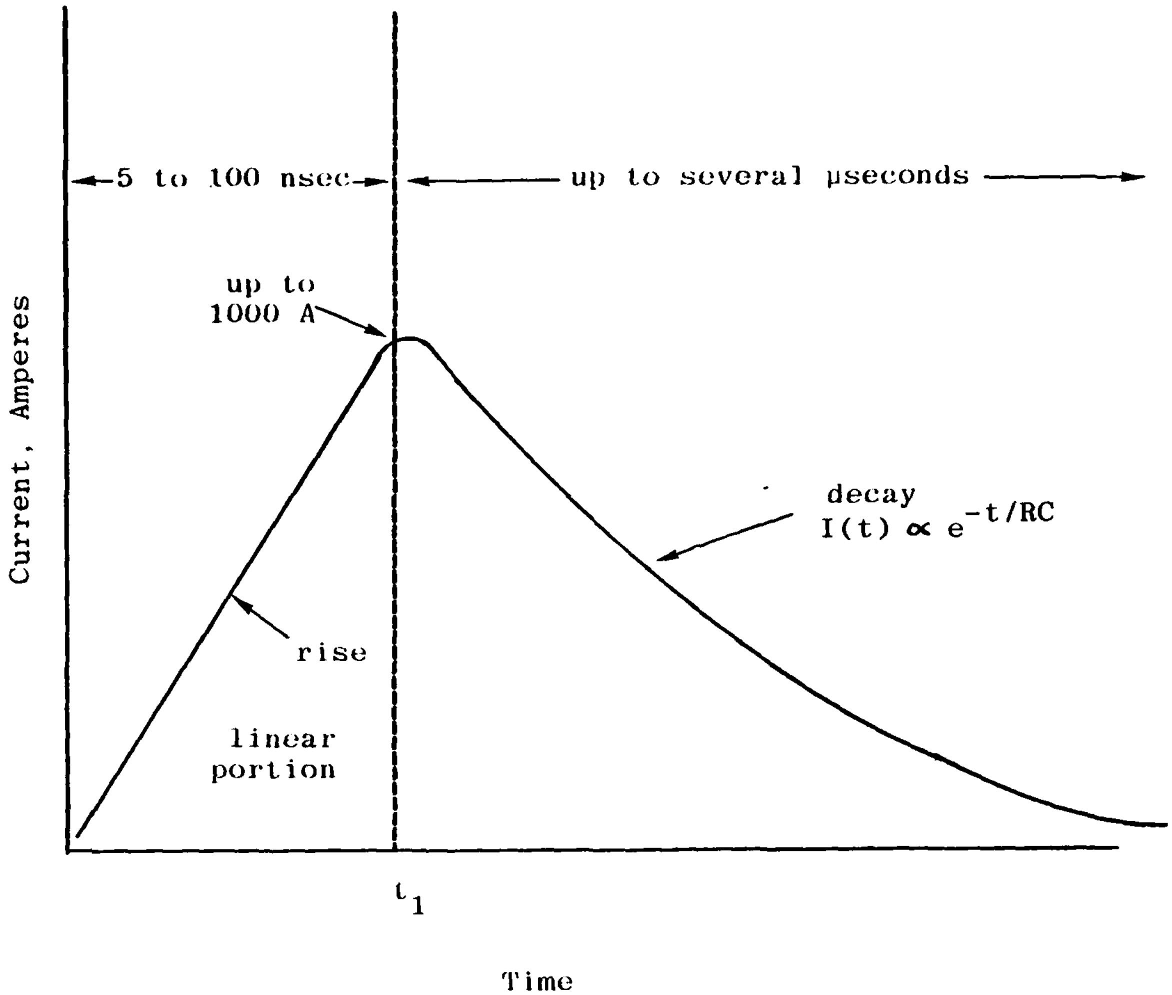


Figure 50.2-1 Discharge Current Pulse Shape

their charging and discharging characteristics in the specified environment. The method of test or analysis is subject to the approval of the procuring agency. Surfaces located internal to the outer space vehicle structure should be shielded from the space plasma environment by eliminating openings in the structure. Material selection should additionally be based on minimizing outgassing and other sources of contamination. Exposed surfaces which are susceptible to effects of enhanced contamination due to SCC should be identified and protected where necessary to assure performance to specified capabilities. References useful to spacecraft material selection include AFML reports: AFML-TR-76-233, AFML-TR-77-174, AFML-TR-77-105, and AFML-TR-78-15.

50.2.5.1 SCC associated differential potentials.

TBD. Tables of "worst case" magnitudes of differential potentials and potential gradients expected for selected S/C materials and material configurations on generic S/C designs will be provided. Potentials will be those derived from analysis using the "worst case" substorm environment (Figure 40.1-1) and compared to P78-2 data.

To date, representative maximum levels as measured on the P78-2 SC1-3 (shadowed samples) SSPM include:

SAMPLE	POTENTIAL (with respect to S/C ground)
Aluminized Kapton	-2.0 kV
Silvered Teflon	-4.0 kV
Astroquartz	-3.7 kV

50.3 Analysis. As part of the SCC protection program, an analytical plan for SCC shall be prepared and maintained. The SCC analytical plan shall be a detailed plan specifying

the SCC analysis program that will be used to achieve conformance with the requirements in this appendix. The plan shall be subject to approval by the procuring agency. The plan shall be implemented to analyze the space vehicle design for susceptibility to SCC The analysis plan should complement the test plan (see Section 50.4) and the analysis should generate data useful to identify susceptible design areas and locations for testing and to quantify representative test levels.

50.3.1 Analysis approach. The analysis should be inclusive of a modeling of the charging of the space vehicle by the specified environment as well as the competing effects of photoemission, backscatter, and secondary emission. Extremes in differential charging levels of the space vehicle and susceptible locations for discharges should be identified. Estimates of discharge characteristics (see Section 50.2.4.1) should be made for the specific space vehicle design of interest, including the actual materials and mounting configuration used in the design. A coupling analysis should be performed relating the EMI and structural replacement currents resulting from the discharges to electrical transients in internal space vehicle cables. In all cases, estimates should be made of the extremes ("worst case") magnitudes of charging levels, discharges, and electrical transients characteristics for the space vehicle design of interest. The analytical program should be made to complement the test program (see Section 50.4) for SCC effects on the space vehicle. In this manner, test levels and test locations should be an accurate representation of SCC effects on the actual space vehicle design.

50.3.2 Analysis procedure. The following procedure should be followed in analyzing the space vehicle for effects from electrical transients induced by SCC. Any analytical

tools or computer codes used shall be described in the analytical plan and subject to approval by the procuring agency.

50.3.2.1 Charging analysis. The specified environment shall be used with space vehicle design features as primary inputs into analytical calculations of the extremes of differential charging for the spacecraft of interest. As a minimum, the analysis should determine:

1. the frequency of occurrence and duration of periods of high charging levels TBD (> 1000 volts)

2. the maximum differential potentials and potential gradients expected

3. the locations of large differential potentials and potential gradients on the space vehicle (candidate spacecraft locations for ESD tests)

(The NASCAP computer code, when validated, will be useful to this analysis).

50.3.2.2 Discharge characterization analysis. The characteristics of discharges caused by SCC are provided in Section 50.2.4.1 for selected material samples and configurations. These shall be used along with associated analysis of the specific space vehicle design of interest and with the charging analysis (Section 50.3.2.1) to estimate extremes of discharge characteristics expected. As a minimum, the analysis should determine:

1. discharge parameters (amplitudes, pulse shape, frequency content)

2. radiated electric and magnetic fields

3. energy content of discharge pulse

4. potential discharge site locations (candidate spacecraft locations for ESD tests)

50.3.2.3 <u>Coupling analysis.</u> The results of the discharge characterization analysis should be used as source terms in an electromagnetic coupling analysis specific to the space vehicle design of interest. Estimates should be made of extremes in magnitude of radiated EMI and structural replacement currents resulting from the expected or specified discharges. The coupling analysis should then determine as a minimum:

1. electromagnetic fields generated interior to the space vehicle due to ESD

2. induced transient pulse characteristics (amplitude, pulse shape, frequency content) for wiring harnesses and sensitive circuits and electronic components

3. identification of susceptible elements in electronic subsystems

50.4 <u>Testing.</u> As part of the SCC protection program, a test plan for SCC shall be prepared and maintained. The SCC test plan shall be a detailed plan specifying the SCC test program that will be used to achieve conformance with the requirements in this appendix. The plan shall be subject to approval by the procuring agency. The plan shall address the test requirements and test methods for subsystems and systems as presented in the following sections. The test plan should be complementary to the SCC analysis plan (see Section 50.3). The plan shall be implemented to test the space vehicle susceptibility to the effects of SCC. Test procedures as presented in the NASA document, <u>TBD</u> (Design

Guidelines Monograph), should be followed where applicable. With the approval of the procuring agency, specific test requirements may be modified to be consistent with the contractor's space vehicle design. Supportive analysis is required to justify the reduction of any test levels below those specified in this appendix.

50.4.1 Test Requirements. The following SCC test requirements are applicable to prototype and flight model space vehicle subsystems and systems.

50.4.1.1 Subsystem Test Requirements. All spacecraft subsystems, components, and their interconnecting cabling shall be subject to the following test requirements.

50.4.1.1 1 Direct Injection. All space vehicle subsystems shall be tested for SCC susceptibility by the direct injection of electrical pulses. The test level shall be TBD (amplitude level) or a level 6 dB greater than the threat level as determined by analysis. The test level shall be subject to approval by the procuring agency. Pulse rise times and pulse widths are TBD (10 nsec rise, 2 μsec width), and the number of test pulses shall be TBD (30 pulses) at a rate of TBD (one per second) or may be established by analysis and subject to approval by the procuring agency

50.4.1.1.2 Critical Test Points. Injection points may be selected from subsystem box input cables or specific pin locations. The test must drive all subsystem electronic components. Injection test locations shall be subject to approval by the procuring agency.

50.4.1.2 System Test Requirements. The space vehicle system shall be subject to the following test requirements.

50.4.1.2.1 Capacitive Direct Injection (CDI). The space vehicle system shall be subject to the CDI of electrical pulses to the space vehicle structure. The test level shall be TBD (amplitude

level) or a level 6 dB greater than the threat level for a blow-off discharge as determined by analysis and consistent with the specified discharge characterization (Section 50.2.4.1). The test level shall be subject to approval by the procuring agency. Pulse rise times and pulse widths are TBD (10 nsec rise, 2 μsec width) and the number of test pulses shall be TBD (30 pulses) at a rate of TBD (one per second) or may be established by analysis and subject to approval by the procuring agency.

50.4.1.2.2 Arc Injection. The space vehicle system shall additionally be subject to the arc injection of electrical pulses to the space vehicle structure. The test level shall be TBD (up to 200 amperes) or a level 6 dB greater than the threat level for a flashover discharge as determined by analysis and consistent with the specified discharge characterization (50.2.4.1). The test level shall be subject to approval by the procuring agency. Pulse rise times and pulse widths are TBD (10 nsec rise, 200 nsec width), and the number of test pulses shall be TBD (30 pulses) at a rate of TBD (one per second) or may be established by analysis and subject to approval by the procuring agency.

50.4.1.2.3 Critical Test Points. CDI test locations and arc injection points shall be selected based on an analysis of the space vehicle design for locations considered the most likely sites for SCC associated discharges. The CDI test must include at least one pulse injection to the S/C common ground structure, and the arc injection must include at least one pulse injection at the solar arrays (if applicable). All test locations must be approved by the procuring agency

50.4.2 Test Methods. The following SCC test methods are applicable to prototype and flight model space vehicle subsystems and systems.

50.4.2.1 Subsystem Test Methods. All spacecraft subsystems, components, and their interconnecting cabling shall be tested using the following methods.

50.4.2.1.1 Test Setup. Direct injection tests on subsystems shall be accomplished in a bench test. The contractor shall assemble all units and interconnecting cabling of a subsystem as closely as possible to a flight configuration. Each subsystem shall be tested independently.

50.4.2.1.2 Test Conditions. Ambient environment testing is adequate. The subsystem should be powered by batteries and operated in representative modes subject to approval by the procuring agency.

50.4.2.1.3 Test Equipment. A pulse generator capable of delivering the specified test levels and pulse shape (Section 50.4.1.1.1) shall be utilized for the direct injection tests. The pulse generator shall be approved by the procuring agency. Tests may take the form of single injection or common mode pin tests, or direct drive of box input cables. All subsystem response and circuit monitoring instrumentation and other test equipment shall be subject to approval by the procuring agency.

50.4.2.1.4 Test Parameters and Susceptibility Analysis. Crucial subsystem test parameters shall be identified by the contractor as measures of subsystem performance and as measures of susceptibility to the direct injection test. The subsystem shall perform to specified capabilities during and after the test. Test parameters and measures of subsystem performance and measure of susceptibility shall be subject to the approval of the procuring agency.

50.4.2.2 System Test Methods. The space vehicle system shall be tested using the following methods.

50.4.2.2.1 Test Setup. CDI and arc injection tests on the space vehicle system shall be performed with the system dielectrically isolated from the ground and removed TBD (several) spacecraft diameters from any metallic walls or large metallic structures. Space vehicle telemetry monitoring instrumentation and other test

monitoring equipment should be located in an electromagnetic shielded enclosure. The space vehicle shall be fully assembled and set up as closely as possible to its flight configuration.

50.4.2.2.2 Test Conditions. Ambient environment testing is adequate. The space vehicle system should be powered by batteries and operated in representative modes subject to approval by the procuring agency.

50.4.2.2.3 Test Equipment. Pulse generators capable of delivering the specified test levels and pulse shape (Section 50.4.1.2.1 and 50.4.1.2.2) shall be utilized for the CDI and arc injection tests. The pulse generators shall be subject to approval by the procuring agency. (Figures 50.4-1 and 50.4-2 represent preliminary schematics for performing the tests.) Test equipment shall be inclusive of system response monitoring instrumentation (all subsystem response monitored via spacecraft telemetry) as well as pulse injection instrumentation. All test equipment shall be subject to approval by the procuring agency.

50.4.2.2.4 Test Parameters and Susceptibility Analysis. Crucial system test parameters shall be identified by the contractor as measures of system performance and as measures of susceptibility to the CDI and arc injection tests. The system shall perform to specified capabilities during and after the test. Test parameters and measures of system performance and susceptibility shall be subject to the approval of the procuring agency.

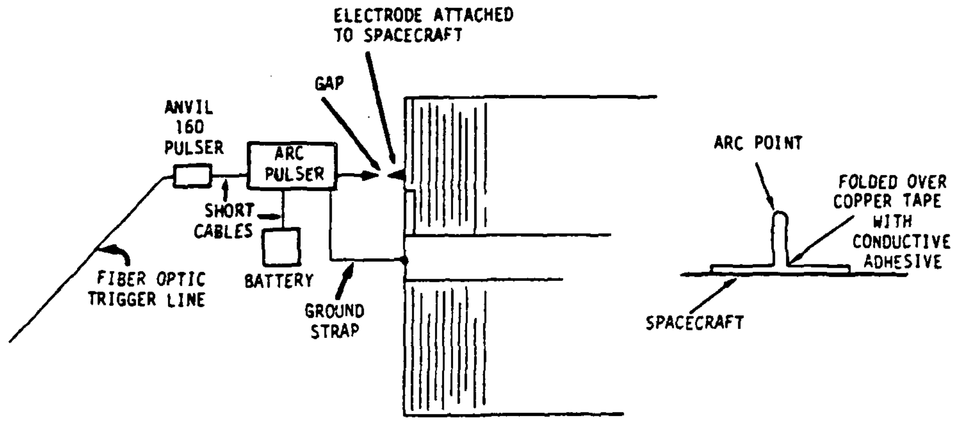


Figure 50.4-1 Arc Injection Schematic

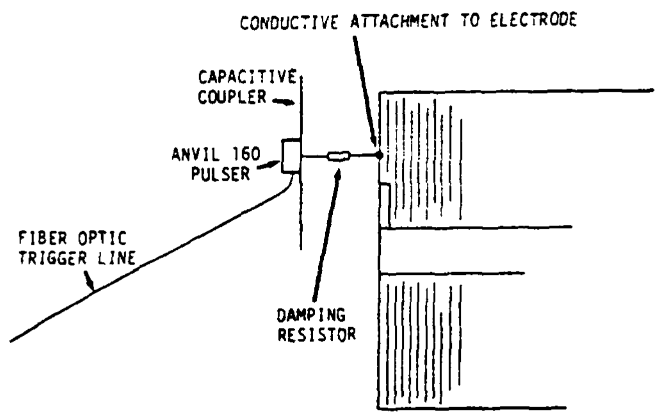


Figure 50.4-2 CDI Schematic

SECTION III
BACKGROUND INFORMATION

1.0 JUSTIFICATION FOR MATERIAL IN SECTION II

1.1 Scope (10.)

The format of the Scope (10.1) and Application (10.2) sections are fairly standard. It is specifically called out, however, that the Spacecraft Charging Requirements Appendix is only applicable to vehicles operating in the regions of space where the plasma environment can cause SCC effects. It is, therefore, mandatory that these regions of space be clearly described with details called out in a reference document. The likely candidate for the referenced information is the final version of the AFGL Environmental Atlas. A statement of the applicability of the Spacecraft Charging Requirements Appendix should also appear in the body of the MIL-STD-1541 revision for completeness.

1.2 Referenced Documents (20.)

Documents included in this list are considered the essential documents currently required for a comprehensive understanding of the SCC phenomena, its effects, and approaches to provide protection to the space vehicle. There may continue to be additions and deletions to this list during the next year. Program offices should be allowed to tailor the level of compliance with the referenced material to meet their specific program requirements.

1.3 Definitions (30.)

The list of definitions and acronyms has evolved during the past two years as a glossary of terms specific to SCC that are not adequately defined in MIL-STD-1541 or other documents or have previously had ambiguous meanings. Dr. Alan Rosen (TRW)

generated several of the definitions and most have undergone a general review by the SCC community.

1.4 General Requirements (40.)

The intent of this section is to state, in general terms, the requirement to establish a SCC protection program. The program should be a combination of incorporating design guidelines and techniques, material selection, analysis, and test to assure the space vehicle will perform to specified capabilities in the SCC hazard. The plasma environment associated with the SCC hazard is specified in this section, and is based on NASA/AFGL preliminary inputs. There is no intent, however, to quantify the performance or the protection requirements in this section, but specifically, SCC analysis and test plans are called for. The detailed requirements are then left for the next section.

1.5 Detailed Requirements (50.)

1.5.1 Performance (50.1)

The precise details of performance requirements must be left to the procuring agency to define in the contract Statement of Work. For that reason, the terms "specified performance" or "perform to specified capabilities" are used frequently in the text. The contractor must address this specified performance in detail in his SCC program plans for design, analysis, and test. The material included in the Spacecraft Charging Requirements Appendix must be written so that it can apply to a variety of space systems.

The detailed requirements for electrical system/subsystem performance calls for returning to specified levels within a telemetry main frame period after the onset of a discharge. The intent here is to minimize the loss of command or data transmittal as well as the need for reconfiguring spacecraft subsystems (clock and logic resets, attitude control, etc.). The need to require minimal degradation in material properties for

thermal control, power, and structure subsystems is obvious. These requirements have been previously reviewed and deemed acceptable by spacecraft contractors and program offices.

1.5.2 Design (50.2)

The design requirements included are considered the basic essential requirements which must be implemented to provide SCC protection, and are considered unique to SCC as presented. The requirements for grounding, shielding, filtering, and materials selection are based on selected design guidelines from the NASA Design Guidelines Monograph (Reference 1). Note that it is called out that the specific design requirements shall be implemented and the other NASA design guidelines should be followed where practical. The text also allows, however, for the contractor to secure waivers from the design requirements if he can show by analysis or test that his design will not degrade if the requirement is not implemented. The analysis or test is naturally subject to the approval of the procuring agency. This is considered appropriate to allow for individual designs that are not amenable to the SCC protection features. Detail for the rationale for the guidelines may be found in Reference 2, "Design Guidelines for Spacecraft Charging Dossier - Volumes I and II", prepared by SAI for NASA/ LeRC, March 1978. A summary of that rationale follows.

1.5.2.1 Grounding

Justification for the grounding design requirements (50.2.1 and 50.2.2) is based primarily on information compiled previously by SAI for the NASA design guidelines documents. Tables 1.5-1 through 1.5-4 provide a summary of this information which was collected primarily from space vehicle contractors. The DC resistance level of ≤ 0.1 ohm for structural elements has been established as a practical requirement from the standpoint of fabricating grounds that will stand up through the vehicle life

Table 1.5-1 Structural Grounding Information Summary

SOURCE	DESIGN ITEM DESCRIPTION	NEED/USAGE RATIONALE	FLIGHT EXPERIENCE AND PERFORMANCE	TESTING	ANALYSIS	IMPLEMENTATION COMPLEXITY	DESIGN IMPACTS	RELIABILITY	DISCUSSION/COMMENTS
Summary	Grounded basic structure, elec. trical boxes grounded to structure, honeycomb and facesheets grounded.	Extension of EMC practices to ESD design.	Extensive flight experience due to EMC practices - grounding of major structural elements	Reasonable DC resistance checks.	Little aside from MIL-STD 1541.	Standard.	Minimal weight impact, little cost.	Good.	Standard practices, not much analysis except for current IRT efforts. Flight experience mounting.
S/C Design (General Info)	Electrically grounded structure, electrical grounding of all exposed conductors and conductive coatings over remaining surfaces.	Basic grounding philosophy, equipotential external S/C surface (primary for experiments).	B SAT, Intelsat IV, ATS 6 results reasonable, NS.333 earth sensor fix.	Point to point conductivity verif. in lab. "Few ohms OK".	Experiment req: Cond. Coatings Bulk resis X thickness $<10^9$ ohm cm^2 (ISFE criteria).	Some difficulties with cond. coatings, adhesives.	Can be costly, some weight impact (not severe).	Probably good.	Very generalized, not much analytical backing behind design decisions. Range of specified resistances from 10 milliohm to several ohms.
Ford Aerospace	Faraday Cage, graphite/epoxy <10Ω, grounding bolts in alum honeycomb, copper wire in graphite/epoxy joints.	As above.	Some. Intelsat V to be flown.	DC Resistance	Little	Not hard	Weight	Good.	General practices.
GE	Rivets through honeycomb 10mΩ structural ground for all metal >2 inches, endbonds if necessary, boxes bolted to structure, basic ground tie <2.5mΩ for chassis, solar array drive shaft grounded.	As above.	Soon BSE, DSCS III.	Good resistance checks.	Some.	Standard 2.5 mΩ ground complexities (crimping, etc.).	Some cost, weight.	Good.	Implemented well, reasonable analysis. Use of Alodine 600 and Dow 19 for corrosion resistance.
IRT	"SCATSAT" model based on MMA Scatha design - electrically grounded main structure welded mesh, metal shims, welded ground straps.	As above.	N/A (in 1 year MMA/Scatha).	Radiated EMI and current injection tests.	Yes	Standard	Weight	Probably good.	See also reference summary 23 in S/C Design References, booms grounded via cable shields.
NRL	Basic grounded structure, "all" metal grounded.	As above.	NTS 2.	Resistance checks.	None	Standard	Weight	Fair.	Basic grounding necessitates - MIL STD 1541 followed.
RI	Boxes grounded to structure, <2.5mΩ, 2 points. Bolted structure.	As above.	GPS - to be flown.	Bond meter verification test.	MIL STD 1541	Standard	Minimal	Very good.	MIL STD 1541 guidelines.
Hughes	Box chassis grounded to structure near box and brought to common structural ground point. Bolted metal structure. Grounded aluminum honeycomb. Copper wire each 1 foot.	As above.	Intelsat IVA and other spinners since 1970	DC resistance.	MIL STD 1541	Standard	Minimal	Good.	Few exceptions.
JPL	Ground all metal and dielectrics unelss ½ CV^2 < 3 mJ. ΔV < 10 volt requirements. Metal inserts in honeycomb.	As above.	Voyager (MJS 77).	Full system ground plane, piece parts in simulation chamber. Test all grounds (< 1Ω).	MIL STD 1541.	Difficult to retrofit.	Cost, weight.	Good - verification during assembly.	Excellent effort for a 4 month retrofit program.

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Table 1.5-2 MLI Thermal Blanket Grounding Information Summary

SOURCE	DESIGN ITEM DESCRIPTION	NEED/USAGE RATIONALE	FLIGHT EXPERIENCE AND PERFORMANCE	TESTING	ANALYSIS	IMPLEMENTATION COMPLEXITY	DESIGN IMPACTS	RELIABILITY	DISCUSSION/COMMENTS
Sperry	Aluminum foil contacting each layer, bolt to assure sufficient contact periphery, close out blanket edges, short wire to structure, bolt, minimum 2 or more ground tabs per blanket (area dependent).	Grounding all metal layers in MLI.	Just beginning to gain experience.	Layer to layer DC resistance checks during fab, blanket to structure res. checks when mounted.	GE analysis appropriate, NASA simulation extensive.	Easiest if in baseline design, moderate complecity but becoming standard practice.	Primarily cost some weight.	Unknown for long term flight, seems good during assembly.	Recommend no crinkling of layers, perforation effects on ESD uncertian.
S/C Design (General Info)	MLI grounding of metallized layers (outer layer, outer 2 layers (symphonie), or all layers).	Eliminate "floating" metal (large areas) near S/C surface.	Several S/C now utilizing varieties of MLI grounding, effective grounds not proven.	Pt. to pt. DC res. at grounding locations, generally no guarantee of elec. continuity across entire surfaces.	Very little done.	Fairly easy if incorporated early in design stage, difficult as "add on" fix, remove wrinkles from blankets.	Minor cost impact, small weight increases.	Seems reasonable but integrity of GND. unproven in space applications.	Interview information has most design details for MLI grounding techniques, resistance < 10 ohms seems okay.
TRW	MLI grounding of top layer only, use 2 mil alum. foil, 3/4" wide, bonded with eccobond 57C, spacer and bolt to secure, at most 2 tabs per blanket.	As above.	777, latest performance seems okay.	Pt. to pt. DC resistance.	None known.	Easy if in baseline design.	Small cost impact weight increase.	Unknown.	Initial 777 fix implemented, adequacy uncertain but seemed to help based on anomaly reductions.
Comsat	MLI ground all layers recommends perforations.	As above.	Some.	None.	None	As above.	Cost, weight.	Unknown.	Avoid exposed dielectric edges, general guide only.
GE	Alum. foil and recessed washer gnd. each layer, generally 2 or 3 gnds. each blanket, 10 Ω wire to ground, edges folded, sewed, taped.	As above, require torque measurements to have sound ground contacts.	Soon BSE and DSCS III TBF.	Yes, resistance checks.	Yes, good analysis.	Not hard, details undisclosed.	Cost.	Probably good	Film metallization at periphery is pt. of failure, bolt through all blanket layers, washer covered, washer 2.5 lineal inches.
Ford Aerospace	MLI GND - use cond. Al tape, no crinkling of layers, GND 1/meter perimeter (min. of 2 grounds each blanket) metal fastener to GND., "foggy" blankets (chemglaze 309).	As above, limit charging	CS satellite NATO III ? Intelsat V	DC, resistance check (few ohm across blanket)	MLI provides ~ .05 dB shielding atten. at 100 MHz.	Not hard.	Cost.	Unknown.	General concerns, not much detail of thought.
NASA/Goddard	Interwoven foil strip or washers, washers - each layer, held by bolt or button, min. 1 strap per blanket.	As above.	ISEE.	Simpson meter DC resistance check.	None.	Not hard.	Cost.	Fair.	Not too sophisticated in approach but may be fairly effective.
NRL	Edges taped, zig zag routing of 1 mil constantan wire.	As above.	NTS-2.	DC resistance.	None.	Not hard.	Minimal.	Unknown.	Seems crude, effectiveness uncertain.
RI	1 point, 1 Mil wire to structure edges closed and folded, ½ mil Mylar/Alum. strips taped and grommet	As above.	GPS to be flown.	Simulation at NASA/LeRC.	None but previous design tested (serrated washer) and discarded.	75% rejection of metallized Kapton due to < 500 A.	More complex than necessary.	Poor.	Ground near middle of longest edge, perforated layers Test Blankets replaced before launch.
Hughes	Interleaved aluminum foil with rivet, wired and bolted to structure. One 3/4" strip per blanket.	As above.	All spinners since 1974 (inc. IVA).	DC resistance on all layers each time blanket is removed.	None.	Not hard.	Minor cost and weight.	Fair.	Early attempts questionable but long history of efforts.
JPL	Interleaved aluminum foil with stainless bolt and washers, wire to structure, 2 per blanket and 1 per m² minimum. Sheldahl black Kapton outer surface	As above.	Voyager (MJS 77).	Inner layers not checked.	None.	Not hard.	Minor cost and weight.	Good. Grounding verification during assembly.	Future designs to include foil back layer for shielding.

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Table 1.5-3 Thermal Surface Grounding (Excluding MLI Blankets) Information Summary

SOURCE	DESIGN ITEM DESCRIPTION	NEED/USAGE RATIONALE	FLIGHT EXPERIENCE AND PERFORMANCE	TESTING	ANALYSIS	IMPLEMENTATION COMPLEXITY	DESIGN IMPACTS	RELIABILITY	DISCUSSION/COMMENTS
Summary	Increased conductivity of surface dielectric materials: conductive transparent coatings, paints, adhesives, silica cloth, wire mesh, and interconnection techniques.	Control spacecraft surface voltage gradients to prevent discharge or provide equipotential surface for experiments.	Mostly to be flown except for paints.	Mostly small module simulation tests.	Little except for materials development efforts.	Ranges from standard for paints to complex for OSR and solar cell cover interconnection.	Can be high cost (interconnections) and weight (silica cloth)	Long term optical and electrical stability of most techniques is generally unknown.	AFML development programs should increase materials selection, reliability, and stability in this area.
S/C Design (General info)	Conductive coatings, grounded metallized surfaces on OSR's, use of cond. adhesives, meshes, cond. paints, silica fabric.	Basic elec. grounding of all exterior conducting elements.	Several features tried in space applications, no guarantees of perf. adequacy	Pt. to pt. DC resistance checks, some lab tests with beam simulations.	Little or none.	Some features very complex, mesh bonding may be especially difficult.	Can be very costly, meshes can have significant weight.	Unknown for most features.	Space environment integrity of many items (cond. coatings adhesives) still uncertain.
AFML	Painted surfaces.	Thermal control (little charge buildup)	Yes, e.g. 291, S13G	GHD tests, quantitative charge levels.	None.	In current use, standard.	Little.	Good.	Outgassing problems, non conducting substrates (limited test data).
	Conductive overcoats.	GHD surface.	Yes, e.g. ITO (Helios).	Not adequate	None.	Very complex.	Expensive.	Poor.	Insufficient full mission testing, not help subsurface charge buildup.
	Silica fabric - steel, C or Al interwoven.	Control of charging < 200 volt levels.	None.	See GE	See GE.	Not hard to fabricate.	Cost, weight.	Excellent.	Required use for exp. satellites where GHD surface, very low potential diff. required.
Comsat	Cond. adhesives.	Hold on OSR's	None with Comsat.	Yes (ground).	Little.	Questionable.	Little.	Fair.	Thickness may be important.
	Kapton tape (conductive variety)	Break up large area shadowed Kapton surfaces.	None.	None.	Little.	Not hard.	Little.	Unknown.	Try to limit discharge levels.
GE	Astroquartz (silica fabrics).	All over ant. shrouds, special applications.	Soon on BSE, DSCS III.	Yes.	Yes.	Standard techniques at GE.	Weight, thermal properties transmittance.	Good.	Seems suitable for many applications, needs desizing (harder to handle)
	Chamfer edges on OSR mirrors.	Cond. coatings grounding improvements.	No.	Some.	No.	Can be complex.	Cost $1 per cover.	Probably good	(see Materials section also)
Nasa/Goddard	Gold grid mesh on Teflon outer layers, .5 inch spacing, 1200 A, .02-.03 inches grid width.	ΔV control for experiments.	ISEE.	Little	Little	Yes.	Cost.	Uncertain, probably o.k.	ISEE experiment criteria < 1 volt ΔV.
	OSR solder weld tab to cond. coated mirrors, cond. epoxy dab, silver wire spring attach.	Thermal control grounded surface.	ISEE.	Some	None	Yes.	Cost.	As above.	Experiment requirements.
	Conductive silicate paints.	Grounded thermal control surface	ISEE, SCATHA.	Space simulation testing & in situ, contactless conductivity	Some.	Standard for silicate paints.	Some - thermal design affected.	Fair.	Ag, too high for < 1 year synchronous application.

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Table 1.5-3 Thermal Surface Grounding (Excluding MLI Blankets) Information Summary (Cont'd)

SOURCE	DESIGN ITEM DESCRIPTION	NEED/USAGE RATIONALE	FLIGHT EXPERIENCE AND PERFORMANCE	TESTING	ANALYSIS	IMPLEMENTATION COMPLEXITY	DESIGN IMPACTS	RELIABILITY	DISCUSSION/COMMENTS
RI	GPS - no OSR's, ungrounded thermal louvers, 3M white velvet paint on back of solar panel and other locations.	Standard thermal surfaces - damage expected.	GPS to be flown	Louvers tested at LeRC - fluttering observed.	Little retrofit.	Standard.	None - no design changes	Poor - antennas & louvers will arc.	Grounding louvers would impact performance.
Hughes	Minimize use of front surface Teflon.	Avoid based on previous test data.	None.	Some (at Malibu).	Little.	Not hard.	Limited low μ_S surface materials available.	Unknown.	Not much change in thermal surface design on spinners due to solar exposure ~ once per second.
	OSR - considering Inconel back with slightly conductive adhesive.	Control OSR arcing.	None.						
	⅛ inch hex mesh bonded to front surface Kapton.	Break up large area dielectric surface.	Pioneer Venus to be flown.						
NRL	Paint on aluminum face sheets, ungrounded OSR's and louvers.	Standard thermal control surfaces no damage expected.	NTS 2.	None.	None.	Standard.	None - no design changes	Poor.	Belief that history does not indicate need for major design changes.
JPL	Vehicle exterior almost all conductive. Sheldahl black Kapton blanket (2-3 MΩ to ground). Small dielectrics okay if ½CV² < 3 mJ. No solar cells (uses RTG). Conductive coatings on transparent optics. Paint on dielectrics overlap to conductive grounded areas (Finch black paint). Radiator - white paint instead of Teflon. *Astromast - metal knuckles grounded, cable wrapped with carbon filled Teflon tape (~60 kΩ/ft).	Experimental vehicle - needed ΔV < 10 volts.	Voyager (MJS 77)	Simulation testing of piece parts.	Extensive - matrix of arc sources versus circuit transient response.	Not hard if included in original design.	Some of these techniques could have severe thermal impact of synchronous.	Good - constant verification during assembly.	Careful evaluation of all surface materials but Voyager is a deep space vehicle. Different techniques may be needed for synchronous.

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Table 1.5-4 Additional Grounding Design Items Information Summary

SOURCE	DESIGN ITEM DESCRIPTION	NEED/USAGE RATIONALE	FLIGHT EXPERIENCE AND PERFORMANCE	TESTING	ANALYSIS	IMPLEMENTATION COMPLEXITY	DESIGN IMPACTS	RELIABILITY	DISCUSSION/COMMENTS
Summary	Ground all metal, multiple point grounding to structure, slip ring ground path across spun/despun interface.	Grounding practices beyond standard EMC.	Present and future flights, not much in past.	Minimal efforts	Little aside from MIL-STD 1541.	Standard if care is taken to identify all metal early in design.	Minor.	Good.	Good EMC practices, currently required for all spacecraft
S/C Design	Ground all cable shields, all metal areas > 25 cm², ground wiring for all units, slip ring carry ground lines through bearing assemblies.	Additions to overall grounded structure.	Several SC, basics to good EMC design.	Generally not much done besides pt. to pt DC resistance checks at various stages.	Little or none.	Most simple and standard.	Minor.	Usually good to excellent.	These items are the basics of sound EMC practices and are generally considered necsssary for all S/C systems.
Ford Aerospace	Single pt. GND returns, 1K - 10K Ω between signal/chassis ground	Proper grounding practice.	Yes, Intelsat V to be flown.	EMC testing	Little.	Standard.	Minor.	Good.	Good EMC practice.
GE	Multiple GRNDS < 1 mΩ on low level digital logic.	Protect sensitive circuitry.	Soon DSCS III.	Hard to do	Unknown.	May be difficult.	Not easy to measure.	Unknown.	Worth investigation.
	Signal/chassis GRNDS brought to box connector - critical analog circuits. GND wire carried with signal wire, multipoint GND-signal elecs. harness shields grounded to box and connector GND.	Good EMC practices.	As above.	GRND checks.	Little.	Standard.	Minimal if done early in design.	Good.	EMC standards implemented well.
RI	All cable shields ground at both ends except some on solar array (28v wire).	Ground external metal.	GPS to be flown.	Probably.	Mil B 5087	Standard.	Minimal.	Good.	External shields only Mil B 5087 grounding spec.
Hughes	Signal line grounds in each box tied to chassis, ground lines brought across BAPIA thru slip rings, residual multiple point ground near BAPIA.	General grounding methods.	Most HAC S/C post 1970.	Ohm meter ground checks.	Mil Std 1541.	Standard.	Minimal.	Generally good.	Latest S/C (INT IV-A, etc.) Have BAPIA ground ties to structure near BAPIA, no long runs in harness. Separation of power and signal grounds as good EMC practice.
JPL	Single path grounding with networks to structure. Some isolated networks. Signal and power can be in same network. Short ground leads from floating sensor heads.	General grounding methods.	Voyager (MJS 77).	Full system, ground plane, and piece part.	Mil Std 1541. Matrix of arc	Standard.	Minimal.	Good.	Standard design, tests and matrix analyses indicated no problems.

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and lend themselves to easy bond meter verification tests. The requirement for grounding all elements exposed to the plasma environment and all with ≥ 25 cm^2 surface area is unique to SCC. Smaller areas, not exposed to the environment directly, should not have sufficient capacitive energy ($1/2$ CV^2) to contribute any discharges of significance.

The requirement for the grounding of their conducting surfaces, especially multi-layer insulation blankets, is also unique to SCC protection. The DC resistance level of ≤ 10 ohms is amenable to several methods of fabricating and testing the integrity of the ground. The recommended number of ground points on conducting surfaces is based on the basic reliability of the bonds in the specified SCC environment (there is some spaceflight experience for this).

1.5.2.2 Shielding

Justification for the shielding design requirement (50.2.3) was also based primarily on information generated in discussions with space vehicle contractors. Tables 1.5-5 and 1.5-6 summarize this information. The level of 40 db shielding attenuation of EMI (100 kHz to 1 GHz)is based on typical shielding provided by spacecraft structures and electronics boxes. The EMI frequency range covers the full spectrum of that expected from SCC discharges. This level may change significantly when a good representation of discharge parameters and EM field characteristics are available (end of FY81). This design requirement will then be uniquely related to SCC discharges and realistically expected EMI levels. It should be noted that the complete shielding of cables external to the spacecraft structure (Faraday cage) is recommended. The contractor is allowed to verify the shielding by test or analysis, while the procuring agency has approval authority over the technique selected.

Table 1.5-5 Primary EMI Shielding Information Summary

SOURCE	DESIGN ITEM DESCRIPTION	NEED/USAGE RATIONALE	FLIGHT EXPERIENCE AND PERFORMANCE	TESTING	ANALYSIS	IMPLEMENTATION COMPLEXITY	DESIGN IMPACTS	RELIABILITY	DISCUSSION/COMMENTS
Summary	Faraday cage, EMI tight electronics units, penetrations shielded.	Attenuation of RF, EMI disturbances.	Some in past, most experience will be on current programs.	Standard EMC testing, Mil-Std-1541.	Primarily attenuation calculations.	Standard.	Primarily weight.	Excellent.	Vacuum deposited aluminum (VDA) is not an adequate EMI shield. Aluminum honeycomb can have some effectiveness.
S/C Design	Faraday cage design and electronic unit EMI tight enclosures, provide 40 to 50 dB attenuations, shielding of penetrations, use of EMI baffling.	Attenuation of RF, EMI disturbances.	Unit shielding standard practice, some designs approaching Faraday cage in use.	Standard EMC testing performed.	Calculations of attenuations for specific shielding configurations, elec. skin depth calculations.	Design as part of basic structure to facilitate implementatin.	Can be severe weight impact.	Generally excellent.	Should be included as part of baseline design. Faraday cage enclosures from two mils to 50 mils recommended.
Ford Aerospace	Faraday cage, all cables, harnesses, shielded.	EMI shielding.	Yes, Intelsat V to be flown.	Little.	Yes, attenuation and coupling calculations.	Standard.	Weight.	Excellent.	Included in baseline design outside boxes only.
GE	Basic box - (50 dB) 30 mil alum. (cond. finish). Faraday cage - DSCS III 30 penetrations (40 dB)	As above.	Soon, DSF, DSCS III	Yes, attenuations checked.	Attenuation calculations.	Standard.	Weight penalty can be severe.	Excellent.	Analysis and test approach good.
IRT	"SCATSAT" model based on MMA SCATHA design - Faraday cage, shielded penetrations (braid or cond. tape), top cavity closeout.	As above.	N/A (In 1 year MMA/SCATHA)	Yes.	Yes.	As above.	Weight.	Probably good.	Combined test/analysis program.
NRL	Electronics boxes interior to aluminum honeycomb structure, apertures sealed with RFI gaskets or honeycomb.	As above.	NTS-2	Mil Std 1541	Unknown.	Standard.	Weight.	Probably good.	May have shielding details which were not worried, strict EMI requirements were supposedly followed.
RI	20 mil alum. Faraday cage except ~ ¼ antenna clearance (covered with MLI) 50 mil electronics boxes.	As above.	GPS to be flown	Unknown (probably Mil Std 1541).	Unknown.	Standard.	Weight.	Good.	Probably Mil Std 1541.
Hughes	No intential Faraday cage but recommends it to be done, generally 40 mil alum. elec. boxes.	As above.	All HAC S/C post 1977	Mil Std 1541	Little.	Standard.	Weight	Fair.	Spinner design not readily amenable to Faraday cage.
JPL	Faraday cage design - 2 mil aluminum foil sheets in regions without aluminum face sheets.	As above.	Voyager (MJS 77).	Mil Std 1541.	Yes, including modeling effects of arc sources on circuits.	Not hard.	Weight.	Probably good.	Analyses to determine retrofit needs. Scientific vehicle with ΔV < 10 volt requirement with conductive exterior.

Table 1.5-6 Additional Shielding Design Information Summary

SOURCE	DESIGN ITEM DESCRIPTION	NEED/USAGE RATIONALE	FLIGHT EXPERIENCE AND PERFORMANCE	TESTING	ANALYSIS	IMPLEMENTATION COMPLEXITY	DESIGN IMPACTS	RELIABILITY	DISCUSSION/COMMENTS
Summary	Cable shields, connector caps, internal shielding, foil shields under MLI, other incidental shields.	RF, EMI shielding.	Some past and many current missions.	Standard EMC, Mil Std 1541.	Attenuation calculations.	Standard.	Weight can be severe.	Excellent.	Unshielded external cables should be filtered upon entry into the spacecraft.
S/C Design (general info)	EMI shielding of all wires, cables, terminators, connectors, feedthroughs. Thickness of shielding application dependent, generally equiv. of several mils of alum. is acceptable. Max. of 5 wires in shield.	RF, EMI shielding for signal, power, ground lines.	Several S/C where required for EMC design integrity.	Standard EMC testing performed.	Attenuation calculations.	Difficult if not planned in early design.	Can be severe weight penalty can impact rework attempts.	Generally excellent.	External (outside of Faraday cage) cabling, etc. should be shielded, internal is optional depending on applications. Some double shielding recommended.
Ford Aerospace	Harnesses, cables connectors	As above.	Yes. Intelsat V to be flown.	Standard.	Unknown.	Not hard.	Weight (little).	Excellent.	Outside boxes only.
GE	Harnesses on exterior 2 mil copper foil on DSCS III, GND shield at both ends.	As above.	Soon - BSE, DSCS III	Some.	Yes.	Not hard.	Weight.	Excellent.	Standard shielding, longitudinal in lieu of spiral shields implemented (external shields only).
IRT	"SCATSAT" model based on MMA MMA design, alum. cap on blocking diodes, all external and internal system wire harnesses shielded, alum. foil inside overall shield, grounded to Faraday cage (braid soldered under foil), pickup cables shielded.	As above.	N/A (in 1 year MMA/SCATHA).	Yes.	Yes.	As above.	Weight.	Probably o.k. good.	Analysis/test program should provide needed information on effectiveness.
NRL	External cables shielded, shield-guided, critical interbox wiring shielded or filtered. Harness routed to spacecraft interior.	As above.	NTS-2.	Mil Std 1541 testing only.	Unknown.	Not hard.	Weight.	Probably okay.	Supposedly strictly followed Mil-Std 1541 RFI, EMI requirements.
RI	All external cables shielded except some on solar array. Batteries are shielded and closed. Exposed connectors are capped.	As above.	GPS to be flown.	Probably Mil Std 1541.	Unknown.	Standard.	Weight.	Good.	SGEMP design philosophy followed.
Hughes	The only harness shields are metallized 2 mil Kapton on external wires.	Environment.	All HAC S/C post 1970.	N/A for ESD.	Little.	Standard.	Minimal.	N/A to ESD.	Not well protected, more dependent on filtering, circuit protection. HAC does recommend avoiding unprotected wires near S/C periphery.
JPL	2 mil aluminum foil sheets under MLI. Foil wrapped cables with ties.	As above.	Voyager (MJS 77).	Mil Std 1541.	Yes.	Not hard.	Weight.	Good.	MLI is not an adequate shield.

1.5.2.3 Filtering

Table 1.5-7 presents a compilation of design information relating to SCC protection through filtering and the use of components and circuits not sensitive to ESD generated transients. The use of filtering is intended as a design requirement for sensitive circuits and components. The application of filters must be consistent with the transients expected (transients with frequency content up to 100 MHz are expected for SCC and observed in tests and flight data to date). Estimates of the pulse shape have been made, but the amplitude level remains TBD (could be > 100 amperes). The discharge characterization along with representative coupling calculations for generic space vehicle designs is necessary to provide adequate justification for the quantification of the filtering design requirement. The SCC associated discharge characteristics (Section 50.2.4.1) should be available by the end of FY81 and will be incorporated in the next update of this document.

1.5.2.4 Materials selection

This is a "common sense" type of requirement, but should be included to direct contractors toward materials selection specifically to avoid SCC effects. Naturally, there are "drivers" in the space vehicle design that demand the use of certain groups of materials, but care in their application can minimize the SCC/discharge effects. It would be impractical to have unique lists of materials that "can be used" and "cannot be used" because of the variety of designs and needs for materials. Tables 7.1-1 and 7.2-1 in "Engineering Analysis Interim Report", SAI CDRL A007, 31 March 1980, summarizes materials development and characterization information pertinent to the material selection process unique to SCC. AFML documents regarding SCC materials applications are specifically called out. The requirement for test or analysis of selected materials to determine their charging and discharging characteristics can also be met by a knowledge of

Table 1.5-7 Additional Electrical Design Information Summary

SOURCE	DESIGN ITEM DESCRIPTION	NEED/USAGE RATIONALE	FLIGHT EXPERIENCE AND PERFORMANCE	TESTING	ANALYSIS	IMPLEMENTATION COMPLEXITY	DESIGN IMPACTS	RELIABILITY	DISCUSSION/COMMENTS
Summary	Filters, clamps, wiring, circuit design, component usage, cable routing, other electronics design items.	Electronics protection for ESD efforts.	Beginning to collect information on current.	Most done by JPL, little otherwise.	Little, some for specific applications.	Difficult as retrofit, some becoming standard.	Weight, cost.	Good.	Unshielded external cables should be filtered. Twisted pair wiring design is effective.
S/C Design (general info)	Use of components, circuits not sensitive to ESD transients, use of filters (and ferrite beads) to remove elec. transients, general concern with some logic, memories, clamps, relays, etc.) minimum bandwidth in circuit designs, careful routing of cables, redundancy of design.	Use insensitive components (to transients) or filter transient pulses or proper circuit design to address ESD.	Scattered flight data available, no complete picture of ESD response performances, some indications of filter effectiveness.	Little or none to ESD transient levels, standard EMC testing only.	Little or none.	Can be difficult, lots of parts to check, may involve considerable circuit redesign.	High attrition rates of components, cost impact and fabrication delays.	Probably only fair due to high variability with in component type.	Some simple filter incorporation is appropriate for specific applications, checking out all circuits and components may be too much to ask. Getting warning flags early to electronics designers can help a great deal.
Ford Aerospace	Latching relays, no CMOS.	Electronics	Yes.	Little.	Coupling calculations.	Done.	Weight, power.	Good.	Use heavy components, avoid sensitive electronics for some applications.
GE	Clamps on sensitive circuits to prevent latch-up, twisted pairs.	As above.	Soon - BSF, DSCS III.	Some.	Little.	Mostly standard.	Weight, cost.	Good.	Worthwhile to implement in specific cases.
RI	Most wires are twisted shielded pairs. No line filters. Solar power filtering in power conditioning electronics.	Circuit design to address ESD requirements.	GPS to be flown.	Unknown.	Unknown.	Standard.	None.	Fair.	No design change for spacecraft charging.
Hughes	Twisted or twisted shielded pair ground returns. Some RFI filters and ferrite beads. Short carefully routed cable runs. Careful wiring within boxes.	As above.	Intelsat IVA, Marisat.	Yes in some applications on flight subsystems.	Little.	Minor.	Minor cost.	Fair.	Recommend high impedance between power and ground including high frequencies. Interior box design excellent from general EMC standpoint.
JPL	R/C filters, diode clamps, current limiting resistors, inductive filters. Metal cover with spring on umbilical disconnect. Weight penalties prevent use of heavy components for electrical hardening.	Retrofit design to protect against ESD effects.	Voyager (MJS 77)	Full system, ground plane, and piece parts in simulation chamber.	Yes, including modeling effects of arc sources on circuits.	Difficult as a retrofit, otherwise not hard.	Weight, cost.	Good.	Concern about electrical stressing of components in system testing.

"past performance" of those materials previously space qualified. The data base of SCC effects or materials is generally available to contractors. The expected extremes in magnitudes of differential potentials (50.2.5.1) should be available during FY81 and will be incorporated into the next update of this document.

1.5.3 Analysis (50.3)

The inclusion of requirements for contractors to analytically determine the susceptibility of their space vehicle designs to SCC has been the subject of debate. Analysis requirements (Section 50.3) have been included in the Spacecraft Charging Requirements Appendix for completeness. It is SAI's recommendation that these requirements be included in the final revision of the MIL-STD-1541 Appendix since a comprehensive SCC protection program should be inclusive of design, test, <u>and</u> analysis. The test and analysis programs should be made parallel and complementary.

1.5.3.1 Analysis approach and procedure

The actual method and depth of analysis has been left to the contractor. This is necessary due to the variety of space vehicle designs and analytical tools that can be applied (see Table 1.5-8). In his overall SCC protection program, the contractor should be able to balance efforts in design, analysis and test applicable to his space vehicle, and result in a comprehensive, cost effective, effort. If, during the next year, specific analytical tools (computer models and analytical codes such as NASCAP) become validated and are of practical use in this analysis, they will be individually required for application.

The basic concept in the analysis approach and procedure is to utilize the specified plasma environment and characteristics of discharges and transient pulses directly applicable to the space vehicle design of interest. This information can then be used to:

Table 1.5-8 Summary of Analysis Tools Applicable to SCC

ANALYTICAL AREA	MODEL/TOOL	ANALYSIS APPROACH AND RESTRICTIONS	VALIDATION STATUS	COMMENTS/APPLICABILITY
SPACE PLASMA ENVIRONMENT MODELS	1) AFGL ENVIRONMENTAL ATLAS (PRELIMINARY)	1) 4 MOMENTS (number density, number flux, energy density, energy flux) provided for preliminary P78-2 data base (44 days) for plasma environment 100 eV - MeV. Correlations with local time and magnetic indices provided. Can be formulated for use as input to sheath/charging models. Data base currently limited and biased toward periods of low charging on P78-2.	1) Basically consistent results between SC5/SC9 data on P78-2 and with previous ATS-5 and ATS-6 data. Needs larger data base.	1) Needs to include definition of space applicable for SCC effects. Formatting of outputs in histogram fashion is useful for contractor use of the data. A clear and simple specification of "worst case" environment is necessary for procuring agencies to include in SOWs.
	2) Others: - LaQuey model - NASA/LeRC spec - TRW model - AFGL preliminary models	2) Restrictive to specific applications. These models have limited data bases which are exclusive of P78-2 data. formats for presentation of the environmental parameters are varied and tailored for specific use.	2) Self-consistent with individual data bases; not very consistent from model to model.	2) Applications severly limited. Not recommended for general use.
SHEATH/CHARGING MODELS	1) NASCAP (NASA Charging Analysis Program)	1) Poisson/Vlasov iteration in three dimensions. Analytical representations for photo- and secondary emissions are questionable for all applications. Level of S/C geometry modeling is good. "Zero" dimensional version (MATCHG) is useful for simple applications.	1) Limited validation for selected material configurations. Currently being applied to P78-2 to compare results to space data.	1) The most comprehensive of charging models yet developed. Needs further validation. May have limitations in applicability due to expense of set-up and computer running time, and strong dependence on accuracy of input parameters.
	2) Equivalent Circuit Models	2) Lumped element electrical model of spacecraft with plasma currents as current sources. Illumination in level of detail of spacecraft design in model.	2) Not validated. Should be applied to P78-2 and compared to NASCAP predictions and space data.	2) Easy to model, inexpensive to run. May be extremely useful to estimate "worst case" magnitudes of charging for generic and specific spacecraft designs. Should be compared to NASCAP to check accuracy of results. Good engineering tool.
	3) Others: - Lee Parker - AFGL - Laframboise	3) Numerical or Monte Carlo solutions for simple geometries (cylindrical and spherical). Limited applicability for real space vehicle applications.	3) Limited comparison to space data (not P78-2)	3) Geometry restrictions too severe. Primarily useful for scientific analysis.

Table 1.5-8 Summary of Analysis Tools Applicable to SCC (Cont.)

ANALYTICAL AREA	MODEL/TOOL	ANALYSIS APPROACH AND RESTRICTIONS	VALIDATION STATUS	COMMENTS/APPLICABILITY
DISCHARGE CHARACTERIZATIONS	1) BEERS DESCRIPTION (Physical model of discharge initiation)	1) Physical model of discharge initiation process, "avalance - induced arc discharges"; electron distribution is high field conduction bands, electron multiplication by avalanche, evolution into streamer, 3-D propagation, current flow, charge release, temperature rise at breakdown. Limited in discharge pulse characterization.	1) Limited, but consistent with some empirical data	1) Description of physical processes leading to *breakdown only*. *Not* applicable to use for space vehicle analysis.
	2) SRI, BEERS (*Phenomenological* model)	2) Measure of transient electromagnetic fields accompanying discharge. Related to structural current flow on spacecraft. Also includes *phenomenological* model of EM discharge, temporal behavior of charge motion during discharge.	2) Consistent with SRI test measurements, not compared to space data.	2) Peak EM field amplitudes have been measured for dicharges from typical S/C materials (Kapton, Teflon, OSRs). Applicability to actual S/C configurations is questionable.
	3) OTHERS - BALMAIN - TREADWAY - JAYCOR - INLAND MOTORS	3) Relates empirical data to measure of blowoff peak current and total charge. Some limited relationship to sample areas also. Some description of blowoff electrons and ions available.	3) Based on empirical data, hypothesized mechanisms.	3) Some utility as "*rules of thumb*" for selected material applications and characterization of discharge parameters. Magnitudes of parameters measured were very dependent on experimental setup.
	4) SAI, BEERS (Discharge characterization -*not yet funded*)	4) Will compile discharge data on various S/C materials, define functional relationships between key parameters, extrapolate to representative plasma environment; prepare a discharge source *specification and* relate source to CDI and arc injection tests	4) Comparisons will be made to P78-2 discharge data as available	4) Direct applicability to S/C Charging Standard in areas of analysis and test. Crucial to determine reasonable test levels and adequate discharge simulation for test.

Table 1.5-8 Summary of Analysis Tools Applicable to SCC (Cont.)

ANALYTICAL AREA	MODEL/TOOL	ANALYSIS APPROACH AND RESTRICTIONS	VALIDATION STATUS	COMMENTS/APPLICABILITY
EMI/COUPLING MODELS	1) IRT (SABER CODE)	1) 3-D Maxwell equation solver, finite difference computer code, used in coupling analysis; directly applicable with minor mods to SCC.	1) Partially thru TINKSAT, SCATSAT tests/analysis	1) Being evaluated for applicability by use with SCATSAT electron irradiation tests at NASA/LeRC. Will provide direct comparison of coupling code predictions and test measurements. Good potential utility to SCC analysis.
	2) SGEMP codes - FAT-3D, MAD(SAI) - MEEC (JAYCOR) - DAVID (MRC)	2) 3-D finite difference EM calculations. Designed for use in SGEMP analysis, could be applied for ESD coupling Excellent for short-time response analysis.	2) Not for ESD	2) Codes are state-of-the-art for SGEMP analysis. Can predict response of simple geometries fairly accurately. Need alternative for long time responses due to computer running time.
	3) OTHERS - SEMCAP (TRW) - IEMCAP (RADC) - ISPICE - SCEPTRE	3) Frequency domain or general purpose circuit analysis codes. SEMCAP, IEMCAP designed for EMI, not transient analysis; others may have problems with multiwire modeling.	3) Not for ESD, but general use is wide-spread	3) SEMCAP has been applied for JPL Voyager programs and ISPICE for Hughes Pioneer/Venus charging studies. Should be used for P78-2 analysis to compare to SCATSAT results and flight data.

- o identify susceptible areas in design (structural and material configurations, grounding and shielding techniques, wiring harness layouts, electrical subsystems, components, etc.)

- o identify candidate locations for discharges (inputs to test program plan)

- o identify appropriate ESD test levels (inputs to test program plan)

It is evident that the analytical activities are important to verification of design for minimal effects from SCC and necessary to properly architect a meaningful test program. This is the basic justification for including the analysis section in the Spacecraft Charging Requirements Appendix.

A summary of analytical models and computer tools with applications towards SCC analysis is provided in Table 1.5-8. More detailed descriptions may be found in Reference 2 and an up-to-date status on model applicability and availability is presented in Reference 3.

Included in the following Section 1.5.4 on testing, various approaches (see Figures 1.5-1 through 1.5-4) are presented for a joint analysis and test program. The level of testing required can be directly related to the amount of supporting analysis implemented.

1.5.4 Testing (50.4)

The testing requirements in the MIL-STD-1541 Appendix for S/C charging are essential in providing the bottom line determination of the space vehicle susceptibility to the phenomenon. As presented in this version of the document, the determination of test locations and test levels depends

significantly on the analysis performed by the contractors. It is considered too stressing to demand that "worst case" test levels must be applied to all S/C designs. Indeed, the necessary justification for recommended test levels is not yet available in the SCATHA program data base. If during the next year, more justifiable and generally applicable test levels become available, they will be given a stronger emphasis in the next update of the SCC Requirements Appendix. The test requirements and test methods included now in the MIL-STD-1541 Appendix (Section II) reflect the best state-of-the-art information currently available with a strong emphasis on "practicality" of representative testing.

1.5.4.1 Test Requirements

Subsystem test requirements are focused on a direct drive of subsystem boxes by electrical pulses representative of transients expected from discharges. There is really no justification for an amplitude level at this time and the contractor can estimate that level (+6dB) and locate critical test points by analysis of his design as discussed in Section 1.5.3.1. If further information becomes available during the next year, a more justifiable maximum level will be included in the test requirements. Reasonable approximations of the time domain waveform of transients are now available and are reflected in the pulse shape estimates. There is really no rationale that can currently be applied to the pulse number and rate. A generally acceptable industry standard is provided.

System test requirements call for both CDI and arc injection testing. The intent is to have the space vehicle respond to the test in a manner similar to that for a blow-off and flashover discharge in space. Again, test amplitudes and locations should be determined by analysis due to the lack of refined quantitative information at this time. The same comments as for subsystems apply for the pulse shape, number, and rate.

The susceptibility of the subsystems and system must be carefully measured against pass/fail criteria for the tests. These criteria have to be carefully derived from subsystem/system performance requirements and must be mutually approved by contractor and procuring agency in the test plan. Tables 1.5-9 and 1.5-10 provide background summaries from the various test programs studied in establishing test requirements as well as the following test methods. The bases for the final test procedures will evolve from the IRT SCATSAT test program.

1.5.4.2 Test Methods

The test setup, test conditions, test equipment, and supporting analysis were derived from the test activities summarized in Tables 1.5-9 and 1.5-10. The contractor is allowed flexibility in designing his own test to meet the test requirements with approval authority to the procuring agency. It is felt necessary that these tests draw significantly on the results of the analyses efforts (Section 1.5.3).

The EMI test requirements and test methods called out in MIL-STD-461A and MIL-STD-462 are very specific for the conducted emissions and radiated emissions referenced. It is naturally the hope that the ESD test requirements and test methods can some day be made specific, but currently the information is not available to quantify the test levels and pulse parameter characterization required. It is also questionable whether such specific test procedures can be developed which are universally applicable to the full variety of space systems to which the MIL-STD-1541 SCC Requirements Appendix is to be applied. In a manner, over-specifying the test procedures may be self defeating in reducing the flexibility allowed to the contractor, and make SPO approval of the document difficult to secure.

Table 1.5-9 Test Methods, Conditions, an

SOURCE	DESCRIPTION	COMPONENT, UNIT, OR SUBSYSTEM PROCEDURES	SYSTEM TEST PROCEDURES	AMBIENT, VACUUM OR OTHER?
Summary	Structural model, qualification model, and flight vehicle discharge testing.	MIL-STD-1541 levels; radiative discharge testing for components and units, unit testing on conductive plane with current injection from discharge, monitor circuit, unit responses, flag and fix sensitive areas. (Qual. units - full level testing, flight units - limited level testing 10%?) Require complete test plan	Structural model testing very useful to flag susceptible design areas, qual. model testing - full level, flight vehicle - limited testing, radiated EMI and current injection both necessary, battery power to vehicle, test locations TBD by analysis, monitor telemetry, require complete test plan.	Ambient okay, screen room preferred dielectric isolation necessary, full scale vacuum irradiations do not appear practical at this time, EM dampers where practical in test chambers.
IRT	"SCATSAT" structural model and "Tin Can" experiments.	N/A	2/3 scale structural model, cruce harness layout, shield currents plotted; initial "Tin Can" tests are for cylinder with dielectric on one end. SCATSAT Irradiation tests in simulated space environment.	Ambient, dielectric isolation from ground, screen room for data. Vacuum test i NASA/LeRC chamber.
DNA/Physics International	"SKYNET" electron irradiation tests	N/A	5 keV X-rays, electron gun irradiations, discharges monitored, S/C hung and grounded through 500 kohm. Qual. model	Vacuum (OW facility)
NRL	NTS-X environmental spec. proposed testing	MIL-STD-1541 levels. E field: 5 V/M, 14 KHz-10 GHz Power line: 1 V P-P primary 50 V RMS secondary Dig. Circ.: 1 V pulse, 10 nsec rise.	Full S/C test with spark discharge - not well defined flight mode.	Ambient - anechoic chamber.
Comsat	Intelsat IV testing (see Hughes information below), monitoring Intelsat V testing (see Ford below).	Support for Hughes style testing of subsystems or units on conducting sheets.	Intelsat V plan for full level test on qual. model 1% level test on flight model.	Ambient, dielectric isolation.
Hughes	Intelsat IV qual. model discharge and current injection tests.	Discharge between conducting sheets caused DCE unit anomaly observed in space, reasonable discharge parameters used, some harnessing included.	Various discharges near and to qual. model vehicle reproduced anomalies and other effects, several methods of excitation used. S/C isolated, battery powered.	Ambient, som in anechoic chamber, dielectric isolation fr ground.

ons, and Instrumentation Background Summary

MBIENT, VACUUM OR OTHER?	RADIATED EMI TESTING, CHARGE REDISTRIBUTION, OR CURRENT INJECTION/TEST LEVELS	THEORY/ANALYSIS BEHIND PROCEDURES	INSTRUMENTATION	COMMENTS
bient okay, een room ferred electric lation necary, full le vacuum radiations not appear ctical at s time, EM mers where ctical in t chambers.	Most reasonable discharge parameter ranges: ~10 to 20 kV potent ~up to 1 joule energy ~10 to 50 nsec rise time ~100 nsec to 1 μsec pulse width ~50 to 1000 A current ~up to 30 sec. at 1 pulse/sec Radiated EMI from spark gap. Direct Discharge into structure. Capacitive Direct Injection, CDI)	Primarily general concepts, some reasonable experience and parallels to SGEMP testing, some trial & error must be expected.	Battery operation fast scopes (batt. op.) current probes & monitors, shielded cables, various spark gap & discharge concepts acceptable, fiber optics useful if available (see IRT referenced summary for detailed instrument list)	Testing should proceed with caution, limited flight unit, vehicle testing is warranted where analytical treatment is comprehensive, MIL-STD-1541, 461. EMI susceptibilities are good baseline: IRT information has best test plan concepts.
bient, dielectric isotion from ound, screen m for data. cuum test in SA/LeRC amber.	Capacitive coupler discharge levels TBD in test plan, "Tin Can" experiment will check drive mechanisms; AD, [illegible]D, CI, ES, up to 10" A.	Based on previous SGEMP treatments, modified SABRE code, initial "Tin Can" model verifications, all TBD.	$E_{\parallel}$, $H_{\parallel}$ shield current monitors, fiber optics, battery powered, fast scopes (>400 MHz), cameras. B probes	Appears to be very useful, awaiting results & comparison to full scale SCATHA testing. Test procedures coming for this program.
cuum (OW . cility)	Charging of S/C surface (solar array) to breakdown, discharges monitored, multiple discharges 200 nsec. apart.	Part of overall SGEMP testing, predictions within factor of 2 of test.	Potential probe, replacement current, possible shadowing by probe, fiber optics for transients signal transmission, strip chart recorder.	Initial attempt at electron irradiations of full scale S/C, 50 cm² discharge areas results applicable to specification.
bient - echoic amber.	Arc discharge 10 kV, 1000A, 1 μsec pulse with 50 sec rise.	Questionable.	Undefined	General testing proposed not well defined.
bient, electric olation.	All forms recommended.	Based on general only.	Undefined - aside from "standard" equipment.	See Hughes and Ford writeups
bient, some anechoic amber, dielectric solation from round.	4 to 7 keV capacitive breakdowns up to 2 joules, discharge in vicinity and direct injection, 5 to 10 nsec rise time, several 10's of amperes.	Based on general concepts, to duplicate space observed anomalies.	Battery powered scopes, current probes, monitored telemetry, no fiber optics.	Initially overstressed. Some units (with discharge > 1 joule energy), backed off to reasonable levels and found some design flaws (e.g.

Table 1.5-9 Test Methods, Conditions, and Instrume

SOURCE	DESCRIPTION	COMPONENT, UNIT, OR SUBSYSTEM PROCEDURES	SYSTEM TEST PROCEDURES	AMB VA OR O
GE	BSE Testing completed. DSCS III testing planned.	BSE: followed MIL-STD-1541, 461. DSCS III conductive plane with subsystem mockup, breadboard circuits also discharges at various distances.	As done to subsystem (BSE) DSCS III qual & flight models esp. at Faraday cage points of entry, no current injection.	Screen dielect isolati Ambient
JPL	Two proof test model tests, one flight Voyager test to verify minimal charging susceptibility.	Boeing test charging of RIG, etc. - not very high confidence.	First test unreliable, second test on electrically "fixed" vehicle. Flight vehicle test all okay (all fixes incorporated). Initial test located design areas which were sensitive, followed MIL-STD-1541.	Screen enviro non-is & isol tests.
FACC	NATO III testing done	N/A	MIL-STD-1541 guide. NATO III discharge in vicinity (radiated EMI), followed Stu Bowers spec.	Ambient
TRW	Test requirements, Fltsatcom test plans (preliminary).	MIL-STD-1541, 461, or EMI circuit susceptibilities should be checked.	MIL-STD-1541, guides qual. model tests: ESD, SGEMP, DEMP procedures. procedures. Discharges at several locations, current injection into corners. Qual. model testing severe, flight vehicle tests undefined - 50 A structural current level considered.	Ambien isolat vacuum ferabl S/C i tion) damper
Martin Marietta	Viking tests results, SCATHA test plans.	N/A	Viking - capacitive discharge through vehicle structure. SCATHA - radiated and direct discharge in 5 test locations.	Ambien dielec isolat
Communi-cations Res. Center	CTS spacecraft tests	N/A	S/C level radiated EMI tests, arrays deployed.	Ambie
Literature & Standards	Testing requirements.	Standard as MIL-STD-1541 guide.	Qual. model recommended to full level, flight models to lower level with analysis.	From to va level with

strumentation Background Summary (Cont.)

AMBIENT, VACUUM OR OTHER?	RADIATED EMI TESTING, CHARGE REDISTRIBUTION, OR CURRENT INJECTION/TEST LEVELS	THEORY/ANALYSIS BEHIND PROCEDURES	INSTRUMENTATION	COMMENTS
Screen room, dielectric isolation. Ambient.	15 nsec rise, 4 sec width, 1200 V/M, .5 joule at 2, 7, 30 cm - radiative, 10 kV DSCS III*- Current injection 10 nsec rise, 40 nsec width, 300 A peak to peak	General principles experience.	Spark gap device digital ohmmeters, EMC-25 MK III receivers, battery powered, good screening.	No sensitivity to discharge > 7 cm (radiative), concern on stressing in current injection tests.
Screened environment, non-isolated & isolated tests.	All three testing stages, 15 kV, 6.5 m joule: arc discharge in vicinity, one end of electrode grounded to S/C - permit discharge & redistribution currents, direct injection.	Some trial & error, drew on experience, monitored transient pulses 100 nsec width, 10 V damage threshold.	Spark gap, antenna pickups, fast scope shielded cables, current probes, similar to Hughes set-up, monitored all S/C telemetry.	Concern over electrically stressing flight vehicles overall testing done. Appears reasonable, results consistent.
Ambient.	Radiated EMI & low level current injection 10 kV, 50 pfd, 2.5 m joule.	6 dB above EMI environment.	Undefined, no current probes, etc,. only telemetry monitored.	Basically Go/No Go testing procedures, Intelsat plans being negotiated with Comsat.
Ambient okay isolation, vacuum preferable (full S/C irradiation) EM dampers	5 kV spark gap, 7 pfd, 1000 A, 200 nsec pulse. Fltsatcom - 10 to 20 kV, 1 pulse/sec, 1000 A, 1 sec. McPherson recommendations: 200-300 A, 2-6 sec. Radiated EMI and current injection, also direct arcing to cables.	EMC, SGEMP, DEMP, BKGND, General principles.	General only, specific instruments undefined, did include microwave datalink.	Full scale S/C testing seems too difficult to accomplish reasonably, facilities not yet available.
Ambient, dielectric isolation.	Viking - 2 kV, .05 fd to structure. SCATHA - 10 kV, 2.5 m joule to structure Much is TBD.	General concepts, some coupling analysis.	Undefined except for standard equipment.	Viking test results verified coupling analysis - Yes/No only.
Ambient.	10 kV, 500 pfd, 2.5 m joule not quantitative on distances, radiative only.	General concepts only.	Standard telemetry monitored.	Cautious test, no output problems observed.
From ambient to vacuum level S/C test with particle	Radiated EMI and current, injection recommended, various levels.	Past specs, and standards.	General	Should be referenced where information is pertinent, test plans included.

Table 1.5-10 Test Analysis and Verifications Background Summary

SOURCE	DESCRIPTION	COMPONENT, UNIT OR SUBSYSTEM ANALYSIS & VERIFICATIONS	SYSTEM TEST ANALYSIS & VERIFICATIONS	THEORY/ANALYTICAL APPROACH	TEST VERIFICATIONS	RESULTS AND CONCLUSIONS	COMMENTS
[illegible]mary	Use of S/C charging analytical models to generate test levels and verification analysis of test results	Should include: o frequency responses o transient amplitudes o shielding attenuation calculations o coupling calculations o flag sensitive circuits, subsystems.	Should include outputs as in subsystem test and analysis and be used to flag sensitive design areas; procedures and analysis must be implemented cost effectively.	Reasonable analytical background becoming available (see analytical modeling section).	Past testing verifications analysis limited.	Inconclusive to date.	Test analysis/verification is necessary to attain confidence in test methodology and results. Program utility is obvious for flagging susceptible design areas. Verification procedures, capabilities are still in preliminary development stages.
	"SCATSAT" analytical modeling and test verifications. "Tin Can" verifications to check stimulation validity.	N/A	SCATSAT electrical model, discharge coupling calculations (modified SABRE code), electrical stimulation validity checks.	Yes - will be done. See analytical modeling, EMI/coupling; ANDRC, SABRE computer code.	Will be done. Comparison of test results to analysis	TBD	Method seems useful, results coming in Summer of 1978 (See also analytical modeling sections)
[illegible]es	"ISPICE" modeling for structural currents and coupling calculations	Performed for DCE unit on conducting plane - calculated representative frequency responses, normalized amplitudes.	Performed for INTELSAT IV Qual. model test simulation, reasonable results for system frequency response, not good quantitatively for amplitudes.	Basic lumped - element electrical model, fairly easy to use and run, (see also analytical modeling sections) shown to be partially consistant with Intelsat IV tests.	Partially - some verification with conducting plane and Intelsat IV testing (BAPTA ground pass problem).	Frequency response predictions good, coupling examples for DSCS III (preliminary) seemed resonable (~ MHz).	Analysis attempted for DSCS III proposal and Pioneer Venus efforts seems generally useful to calculate separations of currents from discharge injection into structure.
	DSCS III charging model based on Inouye (TRW) methods Submodels plasma electrical geometry solar/earth orbit	Did preliminary calculations of dB attenuation provided by boxes (~ 50 dB).	AFGL plasma inputs, calculations of exterior surface charge levels for DSCS III, also Faraday cage dB attenuation (~ 40 dB).	Current balance equations (see analytical modeling sections).	TBD for DSCS III.	High confidence in B.C. solutions to potentials and attenuation calculations.	Did alert design to some areas of large differential charging, maintained high confidence in Faraday cage and shielding approaches to eliminate need for current injection testing
	"SEMCAP" circuit response analysis for Voyager S/C "JINAC" time domain transient characterizations	Electrical simulation of subsystems and circuits, reproduced some responses in agreement to tests	Only as collection of subsystem models.	EMC analysis, difficulty in simulating arc discharge (see analytical modeling).	Partial, good agreement for many circuits to test results	Voltage transients in circuits in subsystems for given discharge impulse	Pulses were fast (10 100 nsec), some massaging of results, 6dB mean difference in analytical and test results.
[illegible] Aerospace	Dipole field arc model. SCEPTRE may be used but not done yet.	N/A	N/A	EMC Guidelines.	No	Dipole arc - 1000A, 10 to 1000 nsec pulse.	Desire arc discharge source based on electric dipole moment.
	Coupling predictions, attenuation from shielding, equiv. circuit electrical modeling, charging modeling.	N/A	McPherson analysis for test levels, structural currents - scoping only.	Refer to section on analytical modeling and reference summaries.	Limited.	Coupling coefficients reasonable, simple models only.	Not easily made useful, most of this is preliminary, potential plans, unverified.
[illegible]n Marietta	Viking analysis of source/field/coupling.	Circuit inductive coupling tests	Corona discharge on Viking gave no improper performance as predicted in analysis	Electric field and inductive coupling equations	Partial, Viking coupling measured	Test/analysis verifications unclear	Not really quantitative verification, only yes/no to susceptibility.

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The test procedures should become more definitive during the next year (this has been tasked to IRT). Through the SCATSAT CDI and irradiation test programs, a variety of test conditions and test equipment have been explored for applicability to representative ESD testing. The equipment used to monitor space vehicle susceptibility to SCC-caused transients should be capable of measuring signals with adequate accuracy to a level of 6 dB below the unit, subsystem, or system requirements. These instruments should provide adequate bandwidth and proper time response to meet the test measurement requirements.

Measured signals should be permanently recorded for later analysis as needed. Use should be made of wideband oscilloscopes, spectrum analyzers, wideband transient detectors, circuit monitors, recorders, current meters and probes, wideband RF detectors and/or other instrumentation capable of monitoring unit, subsystem, or system performance. The equipment used in this testing must have the approval of the procuring agency and be fully described in the applicable test plan. Measuring techniques and instrumentation accuracies should be discussed in the test plan. Any peculiarities in operation, performance, or output in the measuring instruments must be also discussed in the test plan. All space vehicle telemetry equipment, aerospace ground equipment (AGE), EMC test equipment (see MIL-STD-1541) and any specially designed electrical pulsers and SCC measuring equipment used in these tests should be described in the test plan.

The measurements recorded during the SCC tests must be analyzed and used to verify that the space vehicle performs to specified levels. Transients shall be shown to be below upset levels for all critical circuits and components in electrical subsystems. Thresholds for upsets of space vehicle critical circuits and components may be measured at the unit level or calculated analytically. The method chosen is subject to approval by the procuring agency. Protective design features must be

incorporated for all electrical systems to correct any performance below specified levels. The effectiveness of the protective features shall be demonsrated by further test and analysis.

When cost effective and consistent with MIL-STD-1541, the contractor is encouraged to combine analyses and tests in a unified fashion to demonstrate protection compliance to all electromagnetic environments. The relationship of the spacecraft charging requirements to other electromagnetic requirements must be demonstrated to the procuring agency and included in all applicable test and analyses plans.

1.5.4.3 Test and Analysis Approach

The point has been stressed previously that a parallel program of analysis and test is essential to comprehensively address the SCC susceptibility of specific S/C designs. The MIL-STD-1541 Appendix should provide "worst case" specifications for

- the plasma environment
- the differential potentials and potential gradients on a generic S/C
- the discharge signature

The contractor can enter his analysis program at any of these levels and, by incorporation of specifics with respect to his S/C design, can architect a representative program of analysis and test. The various approaches possible go from minimum analysis/ maximum testing to the other extreme of maximum analysis/minimum testing. Table 1.5-11 and the flow diagrams in Figure 1.5-1 through 1.5-4 outline the approaches available to the contractor.

The option of reduced level testing is available to the contractor if he can demonstrate, through sufficient analysis, that discharge and transient amplitudes expected for his specific design are lower than those presented in the "worst case"

Table 1.5-11 Analysis/Testing Approaches

1. Minimum Analysis/Maximum Testing o Accept specified "worst case" charging levels & discharge characteristics o Implement recommended test procedures for discharge testing to full (100%) levels (possibly in steps) o Monitor response to S/C, analyze results, determine susceptibility o Fix, redesign, retest/analysis if required
2. Moderate Analysis/Reduced Level Testing o Analyze S/C design (using charging models & discharge analysis) to determine actual predicted levels; need SPO approval o Implement test procedures to these predicted levels o Monitor response of S/C, analyze results, determine susceptibility o Fix, redesign, reanalyze/test if required
3. Moderate Analysis/Low Level Testing o (Analyze S/C design as in 2.) or accept "worst case" levels o Implement test procedures to fraction (~1%) of predicted or "worst case" levels o Monitor response of S/C as in 1. and 2. o Instrument S/C to measure internal transients in "critical" circuits o Scale measured responses to full predicted or "worst case" levels o Analyze susceptibility of S/C circuits and components to scaled values o Fix, redesign, reanalyze/test if required
4. Maximum Analysis/Minimum Testing o Perform comprehensive analysis of S/C design from environmental inputs → charging analysis → discharge characterization → transients analysis o Predict transients for "critical" circuits o Determine susceptibilities; perform supportive tests if necessary; need SPO approval o Fix, redesign, reanalyze/test if required

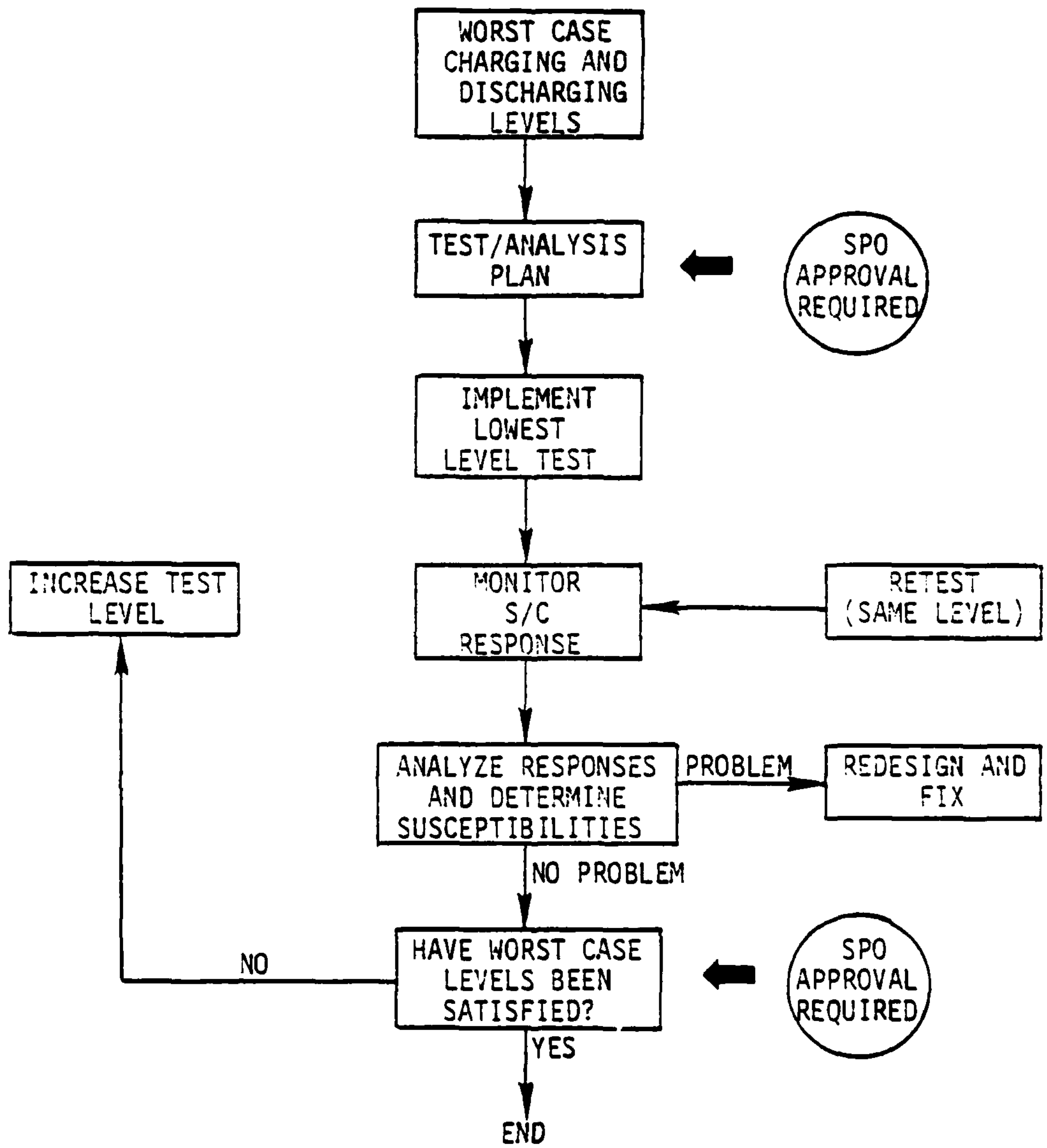

Figure 1.5-1 Approach 1. Minimum Analysis/Maximum Testing

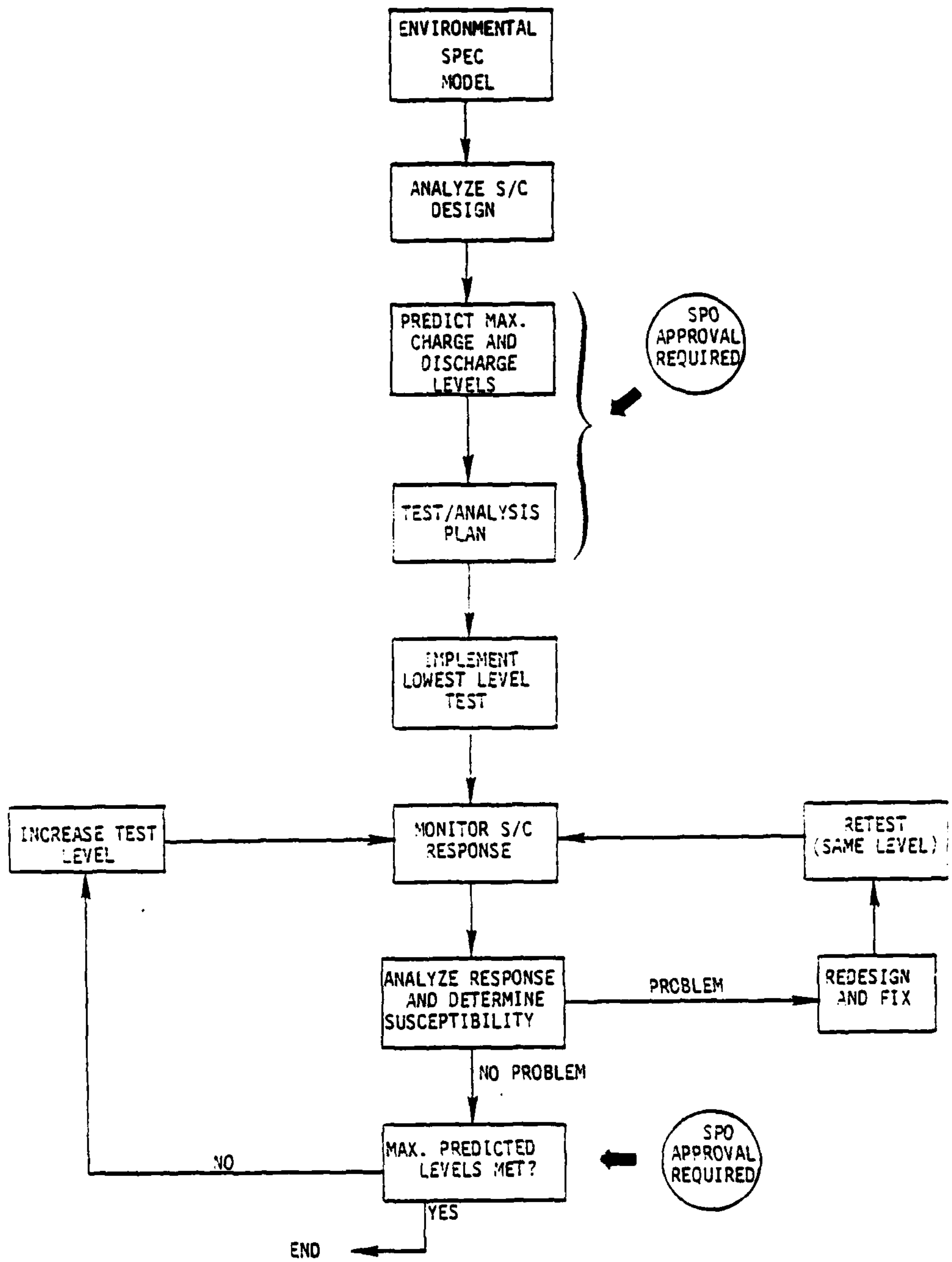

Figure 1.5-2 Approach 2. Moderate Analysis/Reduced Level Testing

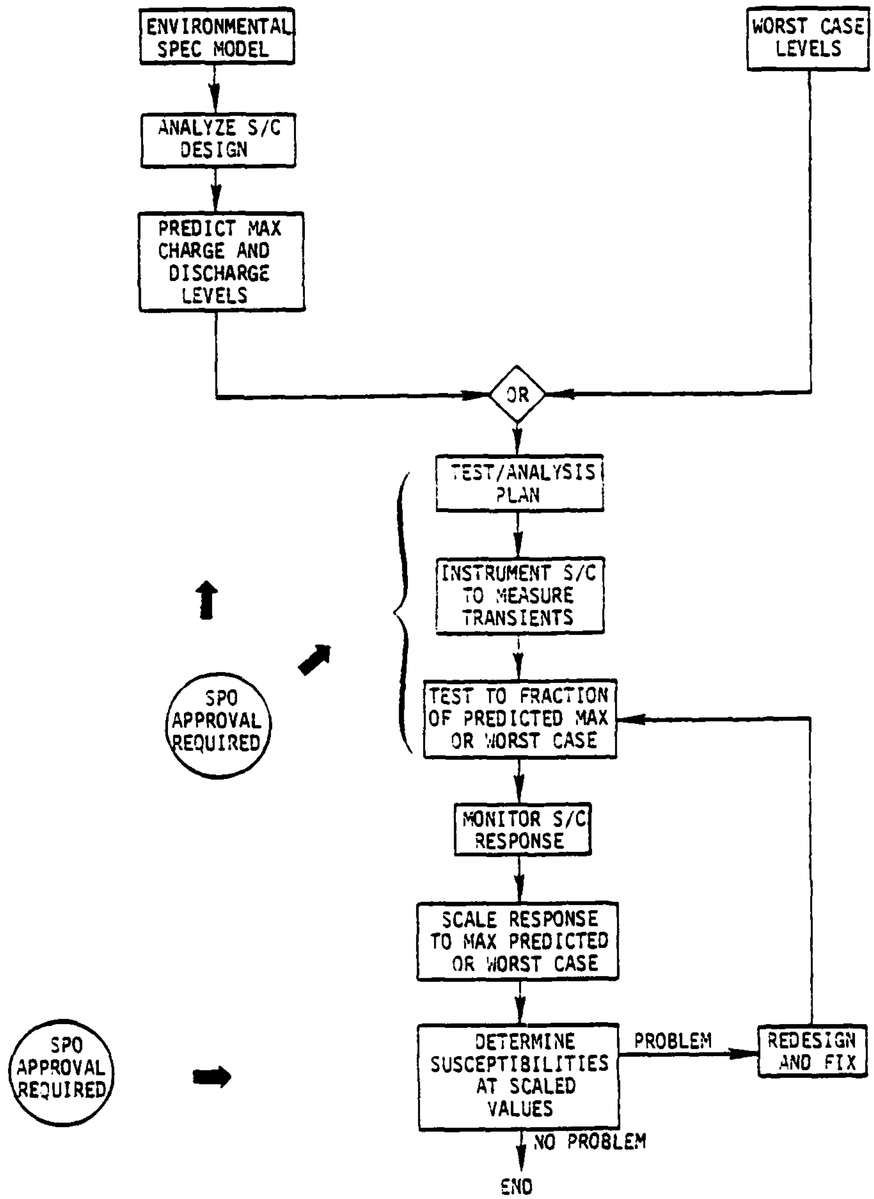

Figure 1.5-3 Approach 3. Moderate Analysis/Low Level Testing

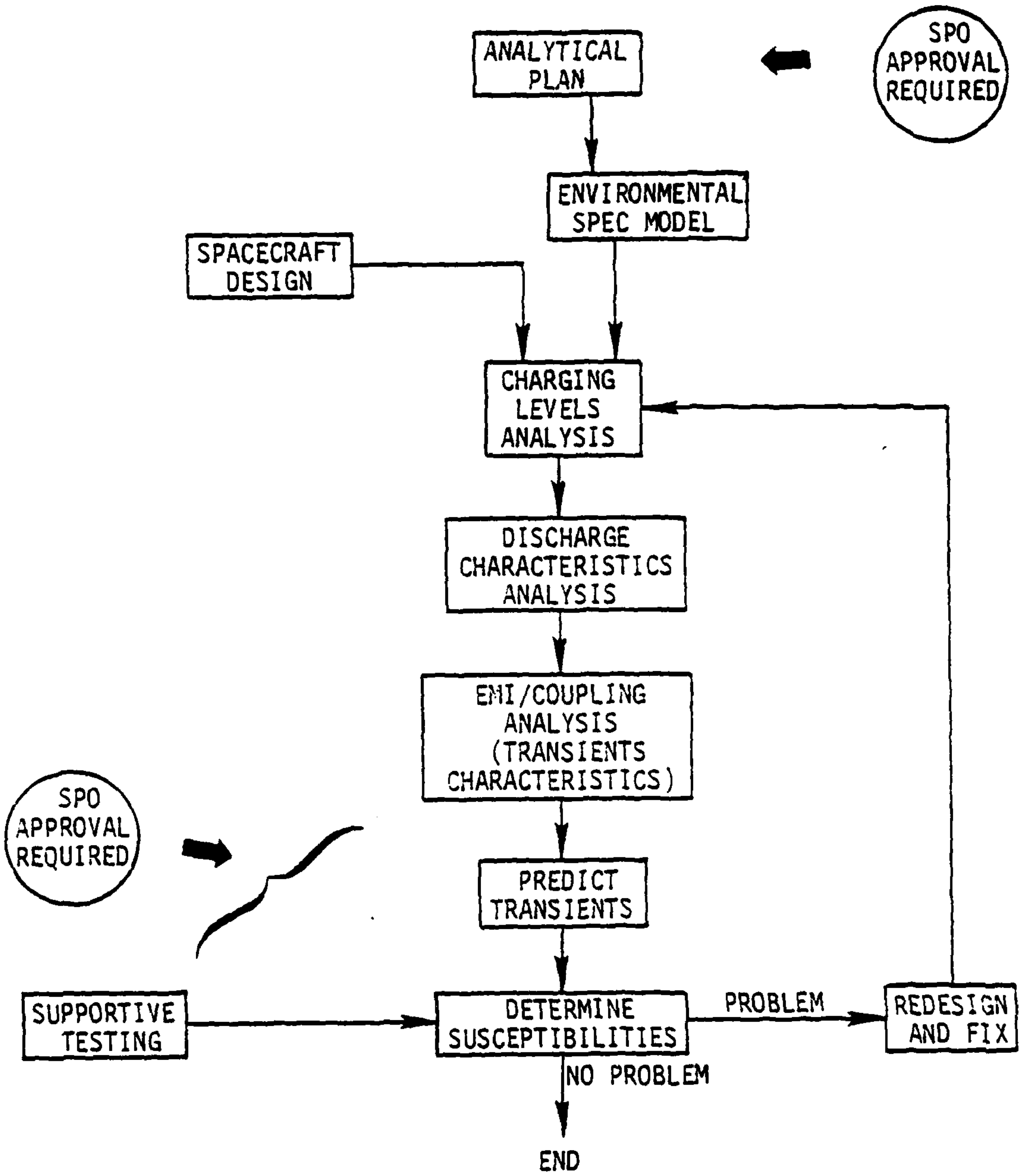

Figure 1.5-4 Approach 4. Maximum Analysis/Minimum Testing

specifications in the MIL-STD-1541 Appendix. It remains for the SCC community to provide the procuring agency with the knowledge to properly assess the contractor's SCC protection program.

2.0 SUMMARY/RECOMMENDATIONS

Several key issues remain unresolved at this time. Any problems regarding the formatting of the MIL-STD-1541 Appendix or the structure of the document can be worked out with AFSD/YLVS and their Aerospace support. SAI would like to concentrate its efforts during the next year, however, on resolving primary technical issues associated with the document and in incorporating the outputs of key program activities (see Section I, 2.0).

It is extremely difficult to refine this MIL-STD-1541 revision so that it pleases or is at least acceptable to everyone. Obviously, there is much controversy over the present document and its contents. SAI has drawn upon a large base of information (see Section 3.0) in developing the MIL-STD-1541 appendix for S/C Charging and SAI has a centralized view of what is needed by the community. This view is inclusive of the interests of SPO/Aerospace, space vehicle contractors and supporting agencies. The technical issues must be resolved among this community and not be biased towards any group. SAI recommends that AFSD coordinate meetings during the next 3 months among SPO, Aerospace, and SAI personnel to iron out the basic content (if not the technical details) of the MIL-STD 1541 revision. Of prime importance is to ascertain the manner in which the "worst case" specifications for the environment, charging, and discharging should be presented, and how to properly incorporate the analysis and test requirements. SAI plans to focus its attention toward these areas in the near term.

3.0 INFORMATION SOURCES

The NASA Design Guidelines Monograph (Reference 1) has a detailed list of over 100 references of spacecraft charging

information. All references have been reviewed by SAI, and SAI has had several discussions with key members of the SCATHA/P78-2 community. The following list summarizes the prime references, recent contacts, and other sources of information which have been useful in developing the inputs to this report.

Key References

1. N. John Stevens, R. Kamen, A. Holman; "Design Guidelines for Assessing and Controlling Spacecraft Charging Effects"; January 1980, NASA document to be published (preliminary draft).

2. R. Kamen, A. Holman, R. Simas, E. O'Donnell, M. Grajek, D. McPherson; "Design Guidelines for Spacecraft Charging Dossier - Vols. I and II", SAI report for NASA Contract NAS3-21048, March 1978.

3. E. O'Donnell "Spacecraft Charging Model Validation/Test Evaluation Status Reort", SAI CDRL A009, Contract F04701-80-C-0009, September 1980.

4. H. Garrett, G. Mullen, et al, "P78-2 SCATHA Preliminary Data Atlas", AFGL Report (draft), June 1980.

5. C. Pike, R. Lovell; "Proceedings of the Spacecraft Charging Technology Conference (1976)", NASA TMX-73537, AFGL-TR-77-0051, 1977.

6. R. Finke, C. Pike; "Spacecraft Charging Technology - 1978", NASA Conference Pub 2071, AFGL-TR-79-0082, 1979.

Other Sources

1. Publications listed in Section II, 20.1, 20.2.

2. DSCS III SPO/Aerospace documents (GE Reports):
   SVS - 1023-B: EMC Plan
   SVS - 9625-B: EMC Performance Requirements
   SVS - 9352-E: EMC, Subsystems and System for DSCS III
   SVS - 9354-C: Grounding, Shielding, Bonding Reports - DSCS III

3. MIL-STD-1541 (and MIL-STD-1541A draft)
   MIL-STD-962
   MIL-STD-462
   MIL-STD-461A

4. IRT: CDI, CAN, and SCATSAT Testing Monthly Status Reports and Final Reports (1978-1980).

5. TRW: S/C Charging EMI Margins Monthly Status Reports (1979-1980)

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